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THE

JOURNAL OF GEOLOGY

SEPTEMBER-OCTOBER, 1902

A QUANTITATIVE CHEMICO-MINERALOGICAL CLASSIFICATION AND NOMENCLATURE OF IGNEOUS ROCKS.

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SUMMARY.

WE present in this work an entirely new system for the classification and nomenclature of igneous rocks, which represents the results obtained after some years of consideration and discussion of the subject in all its bearings.

In uniting our efforts for this purpose we have been actuated by a sense of the seriousness of the responsibility assumed in such an undertaking, and by a conviction that the best results were to be obtained by the co-operation of several workers who agreed on fundamental principles and who were capable of harmonious collaboration.

Originally Professor George H. Williams was associated with us in this work. By his death we have been deprived of a counselor whose judgment we held in the highest esteem, and whose loss we cannot cease to lament.

Many attempts were made to modify in various ways the existing systems of classification in the endeavor to make them answer the demands of modern petrology, and each attempt was successively cast aside on practical trial. It came thus to be perceived by all of us that the main weakness of old systems lay in their fundamental principles and methods and that any new, logical and comprehensive system based on the vast amount of knowledge of igneous rocks acquired in these later

years must be built up from the very beginning on different lines from those heretofore employed. After many endeavors in various directions, we gradually evolved the system here presented. Along with its evolution has gone hand in hand the calculation of thousands of analyses by which it has been tested and its formation in large part controlled. It is a *chemico-mineralogical* system based on its own principles, and is in nowise an attempt to reduce any one of existing systems to a chemical basis or to formulate one of them in a chemical way. Its concepts of rocks are in a large measure new, and hence, except in a very small degree, it demands a new nomenclature.

In brief outline, what we propose is as follows: All igneous rocks are classified on a basis of their *chemical composition*; all rocks having like chemical composition are grouped together. The definition of the chemical composition of a rock and of a unit of classification is expressed in terms of *certain minerals* capable of crystallizing from a magma of a given chemical composition, and the expression is *quantitative.* For this purpose the rock-making minerals are divided into two groups, consisting on the one hand mainly of the more highly siliceous alkali- and calci-aluminous ones, and on the other of the ferromagnesian ones. The first group is called mnemonically the *salic* group, the second is the *femic* group. From this category the micas and aluminous augites and amphiboles are excluded for reasons given in full.

For the purpose of completely classifying a rock by this system its chemical composition must be actually known by chemical analysis, or approximately so by physical means or by microscopic, optical methods indicated by the authors. The thousands of rocks of various mineral compositions and textures whose places in this system are indicated by chemical analysis become types for comparison, analogous to type specimens of zoology and botany, by which similar rocks may be approximately classified.

Since it is known that many magmas may crystallize into quite different mineral combinations, according to the influence of attendant conditions upon the union of the various chemical constituents of the magma, it is necessary to select a certain set of salic and femic minerals as uniform standards of comparison. These standard minerals are, for the most part, species commonly formed, but the aluminous pyroxenes, amphiboles, and micas are necessarily excluded. In practice, the molecular composition of a rock, obtained from its chemical analysis, is computed by a regular method into amounts of these standard minerals, and the place of the rock in the system is then easily determined.

The *standard mineral composition* of a rock is called its *norm*, and this may be quite different from its *actual mineral composition*, or *mode*. Methods for obtaining the latter and for indicating its relation to the former are set forth in detail in the Part III, on Calculations.

On the relative proportions of these two groups of standard minerals, the rocks are first divided into five *Classes*, accordingly as one or the other of these two groups alone constitutes the norm, or is *extremely* abundant; whether one or the other is *dominant;* or whether the two are in about *equal* proportions. The *Classes* thus formed are divided into *Orders* on the relative proportions of the minerals forming the predominant group in each case, and in the middle group on the relative proportions of the salic minerals. Thus in the preponderantly salic Classes the Orders are based on the relative amounts of quartz, feldspars, and feldspathoids.

The *Orders* are divided into *Rangs* on the chemical character of the bases in the minerals of the preponderant group in each case; thus, if these were feldspathic, as to whether they are alkalic, alkalicalcic, or calcic. The lowest division or *Grad* obtains only in the three intermediate Classes, and results from the consideration of the relative amounts of the minerals composing the subordinate group.

In addition to these divisions further ones are provided for where necessary by Subclasses, Suborders, Subrangs, and Subgrads.

Texture is considered of minor importance in classification, and is taken into account after the chemical and mineral composition.

Nomenclature.—The system demands an entirely new nomenclature, and it has been sought to introduce this according to a definite system, the lack of which is so painfully evident in the present nomenclature.

The nomenclature proposed consists of three parts: primarily of substantive names for the magmatic units, implying the chemical composition and the norm, or *standard* mineral composition; secondarily, two sets of adjective terms to be used to qualify the magmatic names; one set referring to the actual mineral composition, or mode, and the other to the texture of the rocks.

The magmatic name consists of a root, derived from a geographical name in all cases except for the names of Classes and Subclasses, and of a suffix. The suffixes are so chosen as to vary in a definite way with the division of the system to which the magmatic name belongs. Thus for Class, Order, Rang, and Grad, the letters *n*, *r*, *s*, and *t* in alphabetical order are used with the vowel *a*, giving in English *ane*, *are*, *ase*, *ate*. For Subclass, Suborder, etc., the vowel is changed to *o*, giving *one*, *ore*, *ose*, *ote*.

The roots forming the names for classes are *sal* and *fem*, mnemonic of the salic and femic minerals constituting their norms, and are combined with prefixes yielding the following: Persalane, Dosalane, Salfemane, Dofemane, and Perfemane.

The roots for the names of the divisions smaller than Class are derived from the names of geographical localities, and as far as possible from those at present in use for rock names, advantage being taken of their connotations as to magmatic character.

The authors propose a nomenclature for field use based on purely megascopic characters.

The work concludes with a discussion of methods of calculating mineral composition from chemical composition and the reverse, and presents tables to aid such calculations.

PART I. CLASSIFICATION.

INTRODUCTION.

The commonly acknowledged unsatisfactory character of rock classifications in present use, and the unsystematic nomenclature of petrography, have convinced us of the necessity for a complete reconstruction of both. Recognizing the magnitude of this task, yet desiring to see it accomplished as early as possible, we have united our efforts toward the production of a new system of classification and the creation of a nomenclature to express it. Many attempts at improvement of existing schemes of classification have been made in recent years, but they have failed to accomplish important results because they have not gone to the root of the matter.

The discussions of petrographers associated with the International Geological Congress have demonstrated the futility of attempting the regulation of petrographical nomenclature without first fixing the basis of rock classification, since the conceptions by different petrographers of the objects to be named are diverse. And the effort to establish a systematic classification of igneous rocks by international conference and agreement has in like manner proved ineffective because of evident inherent difficulties.

The recently published *Compte Rendu* of the Eighth Session of the International Geological Congress, held in Paris, furnishes an illustration of the diversity of views held by European petrographers, while presenting in definite form the convictions of a considerable number of the foremost workers in this science regarding the principles that should govern the choice of bases of a systematic classification. To a very considerable extent we find ourselves in accord with the opinions expressed in the report of the Russian Committee and in the discussions and report of the Paris Commission of October, 1899. And we are encouraged to hope that the system here presented by us will meet with a cordial reception by those petrographers who, sharing more or less completely our conceptions of the fundamental principles that should control the formation of a systematic classification of igneous rocks, may approve of our method of applying them.

We wish to acknowledge our obligations to all those whose ideas and writings have influenced us consciously or unconsciously; influences which will be evident in many places in the succeeding pages. It is not always possible to credit a particular conception to a particular author. The science of petrography has developed so rapidly, and so many workers have been engaged upon kindred problems, that similar ideas have forced themselves upon investigators. Especially, in our own case, frequent interchanges of thought have so blended and modified our ideas that is difficult for any one of us to identify his own.

In particular we acknowledge our obligations to those masters of petrography from whom we caught inspiration for our petrographical careers. To Professor Ferdinand Zirkel and to Professor Heinrich Rosenbusch, our instructors, whose work and thought have opened the way to a host of students of rocks, we are indebted for much that has influenced us in shaping the system proposed, which is in fact a natural outgrowth of present petrographical conditions.

Defects of present systems.—From the review of rock classification in an earlier part of this volume by one of us, it appears that all past and existing classifications of rocks have fundamental weaknesses arising either from the use of theoretical concepts, or from an inconsequent or illogical application of the characters of igneous rocks as bases of their systematic arrangement. That a new nomenclature is required for a new system can scarcely be disputed. The present confusion in petrography is in no small degree due to redefinition of old terms, and to this confusion we have no desire to add. Without going into an extensive discussion of the vitally weak points of existing systems of petrography, upon which all of us have expressed individual opinions, some of the most unsatisfactory features may be briefly stated as follows:

1. There are few definite, clearly enunciated and generally applicable guiding principles, the consequence being that the

present systems are to a large extent arbitrary and subjective, and are capable of being applied differently by different individuals, as is evident from the numerous cases where different names have been given to the same rock, or the same name to obviously different rocks.

2. There is a lack of uniformity in the method of application of existing systems not only among petrographers of different countries, but among those of the same country.

3. The present systems are to a certain extent founded on theory or hypothesis, while classification in order to be stable must eschew all such bases, and be founded only on ascertained facts.

4. Present systems are to a large extent qualitative rather than quantitative, the result being that some given character of rocks is arbitrarily used as a criterion beyond its natural range of application, as, for example, the use of the mere presence of feldspar to distinguish a group of rocks, whether it be the dominant constituent or only a very subordinate one.

5. The construction of modern systems is faulty in that the groups of rocks, or of rock families, now recognized are quite inadequate to express known relationships, and the varying groupings used by different authors are not based upon definite principles, nor are the principles applied uniformly. As a result of this condition, existing systems are highly uneven and it is often necessary to use either too specific or too general terms in naming a given rock.

6. The nomenclature of petrography is quite inadequate to express the relations between the various groups. The single termination makes it impossible to indicate in the name, *per se*, whether it applies to a large or to a small classificatory division, or whether to rocks or minerals, and gives rise to great monotony.

7. As a consequence of these conditions, there is no guide as to when the use of a new name is necessary or justified, each investigator being his own judge in such matters. In some rock groups which have been recently studied, there is an abundance of new names, while in other more common and longer known

groups, a few names are made to do duty for many obviously distinct rocks.

Upon the grounds stated, a new system of petrography seems to us necessary. This conclusion has been reached by us only after many efforts to revise or remodel existing schemes. Our first conferences upon this undertaking were participated in by George Huntington Williams, and our first exchange of suggestions bears the date of May 1, 1893. These efforts on our part, extending over ten years, have brought us from somewhat diverse views to full accord in the system here presented.

BASIS OF CLASSIFICATION.

The progress in the knowledge of the composition, texture, and occurrence of igneous rocks, as well as in the conceptions of the probable causes of variation among different bodies and within one body of rock, has been such as to justify us in considering the problem of the classification of igneous rocks in the light of certain established facts of a general nature. The recognition of these leads to the establishment of general principles upon which a new system of classification may be based.

The facts to be considered may be stated categorically as follows:

The once igneous or molten condition of the magmas from which rocks of this kind have solidified.

The characters of such magmas as solutions.

The physical and chemical properties of such solutions.

The ability of complex solutions to differentiate by osmotic diffusion, liquation, fractional crystallization, or by other processes, under varying conditions of temperature and pressure.

The variations in chemical composition resulting from such differentiation.

The existence of marked chemical variations within igneous masses of small volume in some instances, and of slight variations within bodies of large volume in others.

The absence of fixed proportions of constituents in rocks with two or more mineral components.

The gradations in the chemical and mineral composition of rocks, within limits.

The limited number of the important rock-making minerals.

The existence of rocks having but one mineral component.

The variable crystallization of a chemically homogeneous magma, or of several chemically similar magmas, whereby different combinations of minerals may be produced from chemically similar magmas. In other words, the fact that rocks having diverse mineral compositions may be chemically alike.

The fact that diverse textures develop from the same magma and from chemically similar magmas, and conversely that similar textures develop from chemically different magmas.

The incomplete crystallization of magmas or their solidification into glass in many instances.

The identity of rocks of different geological ages.

The identity of many rocks with different modes of geological occurrence.

The existence of petrographical provinces in which the igneous rocks genetically related are distinguishable from those of other regions, when considered in connection with the occurrence elsewhere of similar petrographical provinces and with the gradual transitions between provinces, should be treated as a larger phase of differentiation. Moreover it has been shown by Brögger[1] that similar rocks may be differentiated from different parent magmas in several petrographical provinces, and may occur in two or more unlike series. That is, rocks belonging to distinct provinces may resemble one another so closely in their dominant characters that they would naturally be defined by the same terms. Hence, we conclude that all igneous rocks should be correlated and classified in one comprehensive system based upon principles common to igneous rocks in general.

The principles which we consider applicable to the classification of igneous rocks, as criteria by which to judge of the facts to be employed and their method of application, are as follows:

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[1] *Quart. Jour. Geol. Soc.*, Vol. L (1894); p. 36, and *Die Eruptivgesteine des Kristianiagebietes*, Vol. III, p. 57, Christiania, 1898.

The classification should be free from hypothesis, and be based only on facts or relations determinable in the rock itself.

The classification should be quantitative as far as possible, and each constituent, chemical or mineral, should be given weight in proportion to the amount present in each case, irrespective of its rarity or unusual occurrence.

The chemical composition of the rock is its most fundamental character, being a quality inherent in the magma before its solidification, and is therefore of greatest importance for its correlation with other rocks.

All rocks of like chemical composition should be classed together, and degrees of similarity should be expressed by the relative positions or values of the systematic divisions of the classification.

The mineral and textural characters, being dependent largely on external conditions attending rock solidification, are to be regarded as of subsidiary importance in classification, but should receive due recognition in the system.

Since it is the chemical composition of the magma that is the fundamental character of igneous rocks by which they are to be classified, only fresh, undecomposed, or unaltered rocks are to be employed in establishing such a classification.

A BRIEF DISCUSSION OF VARIOUS PRINCIPLES that have entered into systems of rock classification is introduced at this place in order to make clear our reasons for selecting those employed in creating the system proposed by us.

Rocks have always been recognized as extremely difficult of systematic classification, because of their infinite variation or gradation from one kind to another in many ways. Reviewing the many factors which may be employed in their classification, they are found to fall into two groups, namely, geological relations, and inherent characters; and the task of the systematic petrographer is to select the characters and apply the criteria which will produce the most natural and stable as well as comprehensive and elastic arrangement.

Of geological relations, the mode of origin is now universally recognized as the first principle to apply to the sub-kingdom of rocks, to secure the grand divisions of which the igneous rocks are one. The further application of geological mode of origin in subdivision of igneous rocks involves the use of theoretical considerations and produces instability of system.

The relations of geological occurrence have been used in the arrangement of igneous rocks, but unsuccessfully. Geological age cannot now be used without violating the known fact that rocks of many ages are identical in their material qualities.

Some systems of classification now in use are based on supposed relationships between the material characters of igneous rocks and their modes of occurrence as geological bodies, which are only partially in accord with facts, and which therefore introduce serious weakness into the foundation of the systems. There are no particular kinds of rocks that invariably characterize geological bodies of special shapes, such as stocks, laccoliths, dikes, etc. Nor is there any specific texture that indicates the depth beneath the surface of the earth at which a rock has crystallized. While there is unquestionably a relation between the texture and mineral composition developed in a given magma and its physical environment during eruption and intrusion and at the time of its solidification, this relationship is so intricate, and the possibilities of environment so manifold, that it cannot be made a basis for classification.

The effort to classify rocks on a basis of their genetic relationships by grouping them in such a manner as to express the fact that all the rocks of a particular center of eruptive action are the differentiates of some common parent magma introduces the utmost complexity, because each group presents a particular set of relations, and it becomes necessary to recognize almost as many groups as there are known centers of eruption. But as already stated, the members of several groups may resemble one another so closely as to be capable of the same definition and deserving of the same name. The consistent application of such a system of grouping would therefore separate rocks which are alike so far as intrinsic qualities are concerned. And this, according to our conception of classification, is not classification. Many of these facts are essential to the complete petrological understanding and description of rocks, but are not applicable to the construction of a petrological system.

The inherent characters of igneous rocks have always been prominent in the formation of petrographic systems, and are plainly the features it is most natural to select. This was specially pointed out by the fathers of systematic petrography, von Leonard and Brongniart, and has been emphasized in recent discussions. Of these characters chemical and mineral composition, structure or texture, are the most important, the others being comparatively trivial or accidental. Structure or texture is now known to depend so largely on variable conditions attending the consolidation of magmas that it can no longer be given the prominent rôle hitherto assigned to it. Chemical and mineral composition then remain as those characters of igneous rocks most available for their classification. Of these, it is to be noted, that while the two are most intimately related, the former is more fundamental, since it pertains to a magma which may consolidate as a glass or become a holocrystalline rock, and in the latter case the mineral constitution varies with attendant conditions.

CHEMICO-MINERALOGICAL CLASSIFICATION.

While the chemical composition of igneous rocks is their most fundamental characteristic, it is known that there is an absence of stoichiometric proportions among the chemical elements or components. It is further clear that there is an intricate interrelationship and serial variation among these components and an absence of chemical division lines, or of groups or clusters of similar combinations of elements. These facts show that any subdivision on a purely chemical basis must be arbitrary, unpractical and unsatisfactory.

All holocrystalline, and many of the partially crystalline rocks derive their most obvious characters from the mineral particles composing them. The varying proportions of unlike minerals in rocks are most striking, and other notable features are due to the physical properties of the minerals, their color, cleavage, hardness, etc., or to the relative or absolute size or shape of the particles. It is by reference to these characters that rocks may be most readily described and identified, and it is then desirable that the systematic classification should be constructed as far as may be by the use of mineralogical data in one form or another.

There are, however, reasons why mineral constitution by itself cannot be used in the principal divisions of a comprehensive and logical classification of all igneous rocks. The existence of vitreous rocks forms one of these reasons, because such rocks cannot be classified at all by purely mineralogical criteria. The fact that a given magma may crystallize into different mineral combinations is another reason. Moreover, if mineral composition were a simple function of chemical composition, and if all rocks were holocrystalline, the number of chemically different minerals of importance would make the task of classifying rocks by means of mineral composition alone practically impossible. It, therefore, appears that neither chemical composition nor mineral constitution can be independently applied to the construction of a logical and practical classification of igneous rocks.

The primary minerals in a holocrystalline igneous rock, when considered *chemically* and *quantitatively*, are a full expression of the chemical composition of the magma, and their exact determination furnishes the chemical composition of the rock. To a large extent the mineral composition may be employed as a means of determining the chemical composition, and since the minerals are readily determinable optically in many cases and are a convenient means of identifying rocks, it is advisable *to treat the chemical composition of rocks in terms of minerals*, and to make the basis of primary subdivisions *chemico-mineralogical.*

While this conclusion is, in its general terms, quite commonly asserted as the purpose of existing mineralogical systems of rock classification, it requires but casual consideration to see that a *qualitative* mineralogical system cannot express chemical composition, and a thoroughly *quantitative* scheme has never been formulated.

Before stating the method of classification to be proposed, it is important to point out some of the chemical and mineralogical relationships obtaining in igneous rocks. And first it is to be noted that while the chemical composition of a magma controls in general the kinds of minerals that may crystallize from it, so that quartz forms in the more siliceous rocks, and olivine in those rich in magnesium and iron, still it does not fix absolutely the kinds or the proportions of all of the rock-making minerals. This is due to the fact that a number of these minerals consist of similar elements in diverse proportions, so that two or more different combinations of elements may be developed in chemically similar magmas. Or, as is well known, some of the minerals having a complex composition may be dissociated into less complex ones. A familiar example is the experimental melting of hornblende and the obtaining in its stead pyroxene and magnetite. Another illustration of the same kind of relationship is the chemical identity of some hornblende-andesites and some pyroxene-andesites.

A striking illustration is furnished by the hornblendite and camptonite of Gran, Norway, described by Brögger.[1] The two rocks having almost identical chemical compositions are composed in the first case of somewhat alkalic, aluminous hornblende, and in the second of less aluminous hornblende and feldspar.

The development of biotite in some rocks and its absence from others having like chemical composition is well known; as shown by its presence in some gabbros and its absence from some chemically equivalent basalts; its presence in certain diorites and its absence from equivalent andesites;[2] its development in minettes and absence from certain basanites. And with this difference in biotite there is a variation in olivine, hypersthene, magnetite and other minerals within the rocks mentioned.

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[1] *Op. cit.*, pp. 60, 93.

[2] IDDINGS, J. P., "The Eruptive Rocks of Electric Peak and Sepulchre Mountain, Yellowstone National Park," *Twelfth Ann. Rept. U. S. Geol. Surv.* (Washington, 1892), p. 653.

Other notable illustrations of different mineral development in chemically similar rocks are the madupite of Wyoming[1] and venanzite of Italy,[2] in the latter rock melilite and olivine appearing instead of pyroxene and phlogopite in the madupite; also the nephelite-syenite of Beemerville, N. J.,[3] and the leucite-phonolite of Bracciano.[4] Indeed, instances of the same kind are well known to all, and are constantly increasing in number. It is therefore indisputable that magmas of identical chemical character may and do solidify as very different mineral aggregates, it being also a possibility that they form on solidification no minerals at all, or that they crystallize only in part.

STANDARD MINERAL COMPOSITION.—Whether vitreous or crystalline, all igneous rocks may be correlated by considering what mineral combinations may be developed from their magmas if completely crystallized. But since several mineral combinations are possible for most magmas, it is advisable to select one of these combinations as the standard of comparison. And for uniformity and simplicity it is necessary to select the same one for all rocks having like chemical composition. This may be termed the *standard mineral composition*, which may or may not correspond to the *actual mineral composition*.

Before presenting the reasons for selecting certain minerals as those best adapted for a chemico-mineralogical classification of igneous rocks, let us consider the important rock-making minerals from the general standpoint of their chemical composition. They may be arranged in several groups chiefly distinguished by chemical characters, but also by associations in the rocks. They are:

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[1] CROSS, W., "Igneous Rocks of the Leucite Hills, etc." *Am. Jour. Sci.*, Vol. IV (1897), pp. 115–141.

[2] SABATINI, V. I Vulcani di S. Venanzo. Rivista di Min. e Crist., Vol. XXII Padova, 1899, pp. 1–12. *Cf.* ROSENBUSCH. *Sb. Berl. Ak.* (1899) p. 113.

[3] *Bull. 150, U. S. Geol. Surv.* (Washington, 1898), p. 209.

[4] WASHINGTON, H. S., "Italian Petrographical Sketches," JOUR. GEOL., Vol. V (1897), pp. 43, 49.

a) *Silica and alumina uncombined,* quartz (tridymite) and corundum, together with zircon, which, though commonly present in very small amount, is oftenest found in rocks rich in silica or alumina.

b) *Aluminous non-ferromagnesian minerals;* orthoclase, albite, anorthite and mixtures of these, leucite, analcite, nephelite, sodalite, hauynite, noselite, cancrinite, and muscovite.

c) *Aluminous ferromagnesian and calcic silicates* (intermediate between *b*) and *d*)): aluminous pyroxenes and amphiboles, biotite, garnet, tourmaline, melilite, some spinels, etc.

d) *Non-aluminous ferromagnesian and calcic silicates:* hypersthene (including enstatite), diopside (including hedenbergite), acmite, olivine (including fayalite and forsterite), and akermanite.

e) *Non-siliceous and non-aluminous minerals with titanosilicates;* magnetite, hematite, ilmenite, apatite, titanite, perofskite, and fluorite, together with the native metals, and certain other metallic oxides and sulphides.

If igneous rocks are considered from the standpoint of their mineral composition, they are found to consist of graduating series of quantitatively different mixtures of several groups of minerals, and since they are all necessary to an exact expression of the chemical composition of the rock, each mineral or group of minerals should receive proper recognition according to its quantitative value. Owing to the number of minerals in most rocks, this is a very intricate problem and we have made repeated attempts to solve it by recognizing several independent mineral factors at one time, involving the problem of handling three or more co-ordinate quantities. This was found impracticable as a basis of classification, and it was seen that the most feasible procedure is to recognize such factors successively according to certain degress of qualities or magnitudes possessed by them in comparison with one another. This has been done by grouping them on a basis of chemical identity or resemblance, and of established affinities or associations, and by successively subdividing these groups by subordinate chemical differences or quantitative values. For this purpose it is necessary to assemble all rock-making minerals into two chemically distinguished groups.

These have been made by uniting quartz, corundum and zircon with the aluminous non-ferromagnesian minerals—feldspars, feldspathoids and muscovite—in one group, and by placing the non-aluminous ferromagnesian and calcic minerals—hypersthene, diopside, acmite, olivine, and akermanite—with the non-siliceous and non-aluminous minerals, and titanosilicates,—magnetite, hematite, ilmenite, apatite, etc.—in the other group.

This leaves the aluminous ferromagnesian minerals to be treated in another manner. The reasons for this separation of the minerals, biotite, amphibole and augite, are discussed at length in a later part of this article, but it may be said here that their variable composition and occurrence, together with the fact that they may be considered as mixtures of aluminous and non-aluminous molecules, make it advisable to defer their introduction into the system of classification until the actual mode of crystallization of the rocks is taken into account. Since it is possible that a magma of any given chemical composition may crystallize without the development of these minerals, and since the chemico-mineralogical expression of igneous magmas is greatly simplified by not considering these minerals until the particular crystallization of the magma is to be expressed, we are justified in omitting them from the two groups of minerals which are to be employed in determining the standard mineral composition of an igneous rock. These two groups of *standard minerals* are:

GROUP I: SALIC MINERALS.

Quartz, SiO_2	Q	
Zircon, $ZrO_2.SiO_2$	Z	
Corundum, Al_2O_3	C	
Orthoclase, $K_2O.Al_2O_3.6SiO_2$	or	F
Albite, $Na_2O.Al_2O_3.6SiO_2$	ab	
Anorthite, $CaO.Al_2O_3.2SiO_2$	an	

Leucite, $K_2O.Al_2O_3.4SiO_2$	lc	L
Nephelite, $Na_2O.Al_2O_3.2SiO_2$	ne	
Kaliophilite, $K_2O.Al_3O_2.2SiO_2$	kp	
Sodalite, $3(Na_2O.Al_2O_3.2SiO_2).2NaCl$	so	
Noselite, $2(Na_2O.Al_2O_3.2SiO_2).Na_2SO_4$	no	

GROUP II: FEMIC MINERALS.

Acmite, $Na_2O.Fe_2O_3.4SiO_2$	ac	P	
Sodium metasilicate, $Na_2O.SiO_2$	ns		
Potassium metasilicate; $K_2O.SiO_2$	ks		
Diopside, $CaO.(Mg, Fe)O.2SiO_2$	di		
Wollastonite, $CaO.SiO_2$	wo		
Hypersthene, $(Mg, Fe)O.SiO_2$	hy		
Olivine, $2(Mg, Fe)O.SiO_2$	ol	O	
Akermanite, $4CaO.3SiO_2$	am		
Magnetite, $FeO.Fe_2O_3$	mt	H	M
Chromite, $FeO.Cr_2O_3$	cm		
Hematite, Fe_2O_3	hm		
Ilmenite, $FeO.TiO_2$	il	T	
Titanite, $CaO.TiO_2.SiO_2$	tn		
Perofskite, $CaO.TiO_2$	pf		
Rutile, TiO_2	ru		
Apatite, $3(3CaO.P_2O_5). CaF_2$	ap	A	
Fluorite, CaF_2	fr		
Calcite, $CaO.CO_2$	cc		
Pyrite, FeS_2	pr		
Native metals and other metallic oxides and sulphides.			

Sal, Fem, and Alfer.—For convenience in subsequent discussion, we will anticipate the question of nomenclature, and introduce here three terms which will be frequently used. To express concisely the two groups of standard minerals and their chemical characters in part, the words *sal* and *fem* have been adopted. The former is employed to designate Group I, mnemonically recalling the *s*iliceous and *al*uminous character of its minerals. *Fem* indicates Group II, since its minerals are dominantly *fe*rro*m*agnesian. As adjectives to express these ideas the words *salic* and *femic* will be used. In certain formulæ employed later the words *sal* and *fem* will be used in the sense just explained, as indicating any one or all of the minerals of the respective groups. Subsequently other mnemonic syllables will be similarly treated.

The intermediate group *c*) of aluminous ferromagnesian and calcic silicates will be designated *alfer* or *alferric* group, this name recalling the fact that these minerals are characterized by the presence of *al*umina and *fer*ric oxide.

Group I.—The minerals of groups *a*) and *b*) have been united to form the salic group (I) because of the well-recognized relations between the development of quartz, feldspar and feldspathoids in rocks and the available silica in the magmas; these minerals forming frequent series of rocks with a regular range of silica. It is also done because of the association of notable amounts of zircon and corundum with these minerals in the more quartzose and feldspathic rocks. And further it is in accord with the stronger affinities of the bases, potassium and sodium, for silica and alumina, which will be discussed later.

The kaliophilite molecule is recognized, since its presence is necessary in a few magmas so low in SiO_2 as not to allow the formation of both leucite and akermanite. Muscovite is omitted from the list in order to simplify the process of calculation. It may be considered as made up of orthoclase with corundum and water. Analcite is also omitted for a similar reason. It may be considered to be composed of albite, nephelite and water. Hauynite is omitted because it may be regarded as calcic noselite, and because it introduces needless complications into the calculation. The standard SO_3-bearing feldspathoid is therefore considered to be a purely sodic noselite. Cancrinite is likewise omitted as being in most cases of secondary origin, as well as for purposes of simplification.

Group II.—The minerals of groups *d*) and *e*) have been united to form the femic group (II) because of their freedom from alumina and their association in notable amounts in rocks low in silica and alumina. They are in this sense antithetical to the salic minerals.

Wollastonite ($CaSiO_3$) is added to the list of femic minerals in order to simplify the calculation of standard minerals in rocks rich in calcium, which may actually enter aluminous molecules, such as garnet.

The simple metasilicate molecule $Na_2O.SiO_2$, analogous to that of wollastonite, is assumed to be present in rocks in which there is an excess of alkalies over Al_2O_3 and Fe_2O_3. It appears in the arfvedsonite molecule, which develops in such rocks. But this mineral, being alferric, is not included among the standard minerals for reasons already given.

In like manner the simplified *akermanite* molecule, $4CaO.3SiO_2$, is included among the standard minerals in place of melilite, because of the alferric character of the actual melilite, our uncertain knowledge of its real composition, and its complexity. The Na_2O and Al_2O_3 with $2SiO_2$ of melilite are calculated as entering into a nephelite molecule, the Fe_2O_3 is referred to magnetite or hematite, leaving the CaO, partly replaced by MgO, and the remaining SiO_2 in approximately the akermanite ratio of 4 : 3. The introduction of this molecule into the calculation is necessary in rocks so low in SiO_2 that a subsilicate must develop.

The molecule $(Mg, Fe)O.Fe_2O_3.SiO_2$, which is characteristic of augite, has been omitted for the reason that the ferric oxide is largely replaced by alumina, and because its introduction complicates the problem of calculation.

Method of calculation.—In order to determine the kinds and amounts of standard minerals that may express the composition of a given rock, to establish its place in the system, we may proceed by a consideration of its chemical composition as given by chemical analysis, or by a consideration of its actual mineral composition as determined by optical investigation, or we may compare it with known rocks whose compositions have been previously determined.

And since it is advisable to select the same mineral combination for the basis of comparison of chemically similar rocks, as already stated, and since there are gradual transitions among igneous rocks, it is necessary to follow the same method of procedure in calculating the kinds and amounts of the standard minerals for all rocks. The method adopted by us is explained in detail in a later part of this paper. It is based upon certain well-known chemico-mineralogical relations affecting the salic and femic minerals, both as regards the proportions of their chemical constituents, the relative affinities of the bases for silica, and the frequent associations of certain of the rock-making minerals.

The method has been developed by considering, first, the chemical composition of igneous rocks, and by devising a plan for the calculation of standard minerals from it. Then, the *actual* mineral composition of holocrystalline rocks has been taken into account, and a plan devised, after reckoning the proportions of these minerals, for estimating their approximate chemical composition and from these data calculating the *standard* mineral composition of the rock.

It is evident that rocks that are not holocrystalline, or those in which the proportions of the actual minerals cannot be determined, must be classified in the first instance by means of chemical analysis. Subsequently similar rocks may be classified with greater or less precision by comparison with rocks having similar textures and the same actual mineral compositions, which have been analyzed chemically.

In comparing the relative quantities of different minerals in rocks, either their mass or their volume may be made the basis of comparison. In calculating the mineral composition from the chemical composition of the rock, the mass is the natural unit of comparison. The same is true if mechanical separation of the mineral constituents is undertaken. When a comparison is made by the eye, megascopically or microscopically, the basis of comparison is volume. This may be transformed into mass by multiplying the volume by the specific gravity of the mineral. The optical methods of estimation being less exact than those first mentioned, the basis of comparison should be mass.

CONSTRUCTION OF THE SYSTEM.

It is proposed to arrange igneous rocks by a system which shall express their quantitative chemical and mineral constitutions. With the known range and degree of variation in these characters it is plain that any system of classification must be arbitrary.

As has been pointed out, the efforts to express the quantitative variation in rocks by means of several variables have shown that such a method is undesirably complicated. And we have sought to find a way for making groups of different taxonomic value by subdivision in a dichotomous manner based on the comparison of successive pairs of factors, since the simplest mode of construction is best.

The mineral constituents of igneous rocks may exist in all proportions from 0 to 100 per cent. whether considered as part of the whole rock, or as part of the group of standard minerals to which they may belong. For example one rock may consist entirely of feldspar, while another has none. And there are intermediate rocks containing all possible percentages of feldspar between these extremes. There are equally wide ranges for some of the chemical constituents, considered either with reference to rocks or to mineral groups. Thus the feldspars of one rock may be wholly alkalic, those of another wholly calcic, and between these extremes there are all possible gradations. Among alkalic feldspars are those purely potassic, others wholly sodic, besides all possible intermediate mixtures of these.

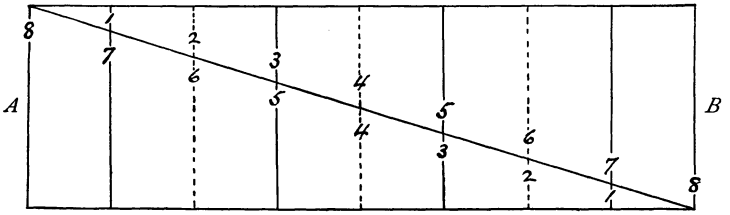
On account of the absence of natural division lines in such series of two variable factors, it is necessary to establish arbitrary divisions. We have accomplished this by considering certain simple proportions as *center-points*, about which variations may be allowed within limits, which limits become the boundaries between petrographical units.

The simplest proportions are: first, those two in which one factor constitutes the whole, and the other factor is absent; second, that in which both factors are present in equal amounts.

Other center-points should be selected with equal respect to these, and may be placed either midway between the three just mentioned, or at shorter intervals. It has appeared to us best to select those midway between the first three, namely, at points representing the proportions three to one, and one to three, making in all five divisions.

It will be noted that the rocks, or mineral or chemical groups, corresponding to the center-points of these divisions seem to have a special value as classificatory types, but we wish to point out that this is not actually the case. Such rocks or such groups, are not more important, considered quantitatively, than those occurring in any other part of the system, even on the boundary between neighboring divisions.

This fivefold method of subdivision may be expressed graphically as follows:



These divisions or units may be described as:

I. One in which the center-point is where the first group is present alone, 8:0.

II. One in which the center-point is where the first group is three times the second, 6:2.

III. One in which the center-point is where both groups are present in equal amounts, 4:4.

IV. One in which the center-point is where the second group is three times the first, 2:6.

V. One in which the center-point is where the second group alone is present, 0:8.

The dividing lines between these center-points will occur at the following ratios: 7:1, 5:3, 3:5, and 1:7. The ranges of the five divisions are given by the expressions:

$$\text{(I)}\frac{A}{B}>\frac{7}{1},\quad \text{(II)}\frac{A}{B}<\frac{7}{1}>\frac{5}{3},\quad \text{(III)}\frac{A}{B}<\frac{5}{3}>\frac{3}{5},$$

$$\text{(IV)}\frac{A}{B}<\frac{3}{5}>\frac{1}{7},\quad \text{(V)}\frac{A}{B}<\frac{1}{7}.$$

The divisions may be defined in general terms as:

I. In which A is alone present or is *extremely* abundant.
II. In which A *dominates* over B.
III. In which both A and B are present in *equal* or *nearly equal* amounts.
IV. In which B *dominates* over A.
V. In which B is alone present or is *extremely* abundant.

The factor which is extreme or dominant over the other, will be spoken of as *preponderant*, the other being *subordinate*.

To indicate whether one of a pair of factors is present in greater or less amount than one-eighth of the combined pair of factors, that is, $\frac{A}{B} \gtrless \frac{1}{7}$, we have adopted the terms *notable* and *negligible*. The former means that it is present in greater amount, and the latter that it is present in less amount, than that proportion.

It is to be noted that the smallest amount of any factor which we recognize as *notable* in a particular division of the system is one-eighth of the combined pair of factors, not necessarily one-eighth of the whole rock, since the pair of factors may be a fraction of the entire rock.

This fivefold method of subdivision will be further applied to that factor of a pair which is *extreme* or *dominant* over the other, or, in the case where both are present in equal amounts, it will be applied first to that one which is deemed to be of the greater importance, and subsequently, when necessary, to the less important factor.

In the case of one factor which is subordinate to another, but not negligible, $\left(<\frac{3}{5}>\frac{1}{7}\right)$, such a manifold subdivision is not advisable, since one-fourth of the factor in question would be less than one-eighth of the pair, and hence negligible. In this case we have adopted a threefold division, by retaining the central division of equal proportions $\left(<\frac{5}{3}>\frac{3}{5}\right)$, and uniting the dominant and extreme divisions. In these divisions there is one where two factors are equal or nearly equal $\left(<\frac{5}{3}>\frac{3}{5}\right)$, and two where one factor dominates or is extreme $\left(>\frac{5}{3}\right)$. Strictly, the subdivision here should be into thirds, but, in view of the confusion liable to arise from the change in proportions the method adopted seems the most advisable one.

No subdivision need be made of a factor which is present in negligible amount, the other factor being extreme, since the whole subordinate factor falls within the allowable limit of variation.

It may be noted in this place that certain prefixes are used in connection with mineralogical and chemical terms to indicate that a factor is *extremely* abundant, or is *dominant.* In the first case the prefix is *per.* In the second case it is *do* or *dom.* When comparison is made on a threefold basis, and one factor *predominates* over another $\left(> \frac{5}{3}\right)$, the prefix is *pre.*

Since this classification is largely a chemical one, and since in all the calculations of minerals the molecular amounts of each constituent only are used, it must be borne in mind that all chemical comparison is made on the basis of the relative number of molecules, that is, it is purely molecular. For this purpose all percentages in analyses must be reduced to molecular ratios, by dividing each percentage by the proper molecular weight.

OUTLINE OF THE SYSTEM.

The subdivisions of igneous rocks proposed by us, based upon the principles discussed in the preceding pages are as follows:

CLASS, SUBCLASS.
ORDER, SUBORDER.
RANG, SUBRANG.
GRAD, SUBGRAD.

The word *Rang*, which is an obsolete form, equivalent to *Rank*, has been chosen instead of *Rank* to avoid confusion, since it is desirable that the technical term should differ from one which is in common use for other purposes. The same is true of *Grad* which is an old form of *Grade.*

The four terms — *Class, Order, Rank* and *Grade* — were at first selected because they are of the same category, the first two being commonly used in classification. But Rank and Grade are so frequently employed in a general sense that it is advisable to substitute archaic forms in their stead.

These divisions, which are successively smaller, are based on characters of the magma of less and less importance. In other words, the highest divisions express the broadest and quantitatively most important magmatic characters, those next to them less important ones, and so on. It has been our aim to select the sequence of characters in accordance with this plan, and also to have homologous divisions throughout the system based on the same kinds of characters.

The broadest distinguishing chemical characteristics are expressed by the aluminous non-ferromagnesian minerals and their associates, quartz and zircon, the *salic* minerals, on the one hand; and by the ferromagnesian non-aluminous minerals and their associates, titanite, apatite, etc., the *femic* minerals, on the other.

Consideration of the salic and femic mineral groups shows, however, that the former is more simple in composition than the latter, so that certain modifications, not of the principles, but of their application, will be necessary in places.

Thus the salic minerals are composed chiefly of SiO_2 as representing the acid radical, with small amounts of Cl and SO_3 in the sodalite group, and of K_2O, Na_2O and CaO as representing the bases, these last being always accompanied by an equal amount of Al_2O_3, except in the sodalite group, where this is slightly less than the soda. The alumina, in most cases, reckoned among the bases, may play the rôle of acid to some extent in certain cases. On the other hand in the femic minerals, leaving apatite, fluorite, sulphides, etc., out of account, SiO_2, Fe_2O_3 and TiO_2 represent the acid radicals (the last two possibly uncombined with a base as hematite and rutile), and K_2O, Na_2O, CaO, MgO and FeO represent the bases.

Consequently, to keep to our system of two factors, already described, a more numerous subdivision of the divisions in which the femic minerals preponderate is necessary. But, as will be seen, this can readily be done without transgressing the general principles on which the system is based or affecting the homologous characters of the various divisions in different parts of the scheme.

The principles on which the divisions enumerated above are made may be stated as follows:

Class.—This, the broadest division, expresses the most general chemico-mineralogical character of the magma, and is therefore based on the relative proportions of the salic and femic mineral groups as calculated in the standard mineral composition of each magma. In Classes all the salic minerals calculated for a magma are contrasted with all the femic minerals.

Subclass.—This division is based on certain broad chemical distinctions in the salic and femic groups, which make it possible to divide each of them into two parts. These will be explained in detail when these divisions are described at length later.

Classes and Subclasses exhibit the broadest and most general characters of the magma, and are based only on the salic and femic mineral groups, and the parts into which these may be most broadly divided on certain chemical lines. More special chemical characters of the salic and femic minerals in each class are next to be distinguished, and since both cannot be indicated at once, according to our principle of dealing with only two factors at a time, we consider first one group of characters and then the other. In accordance with the principle of giving importance to constituents on the basis of their relative proportions, the characters of the preponderant group, salic or femic, will be considered first until they are fully described, and then those of the subordinate group, femic or salic, will be taken up. The divisions from Order to Subrang are based on the chemical characters of the preponderant standard mineral group, while the divisions from Grad to Subgrad will be based on the chemical characters of the subordinate mineral group.

Order.—The salic minerals being in the great majority of cases silicates and quartz, and the silica being the most abundant component of these silicates, it is quantitatively the most important chemical character of the salic minerals. Moreover the femic minerals in most rocks are silicates, and in them also silica is quantitatively the largest factor. Less abundant femic minerals are ferrates, titanates, and silicotitanates, besides still less frequent minerals of other kinds.

For these reasons the chemical characters of the salic and femic minerals of first importance quantitatively are the acid components, SiO_2, TiO_2, Fe_2O_3, which might be expressed uncombined with bases, or by mineral molecules. In order to express as far as possible the mineral composition together with the chemical it is advisable to express the relative amounts of these acids by means of mineral subgroups.

Orders in Classes with preponderant salic minerals are consequently based on the proportions of quartz to the feldspars, and of feldspars to feldspathoids, since these proportions correspond to differences of SiO_2 in the salic minerals. In Classes with preponderant femic minerals Orders are based on the proportions between silicate and non-silicate minerals in the first instance, and the recognition of the other acid components occurs in subdivisions of Orders.

Suborder.—In those Orders in which there are preponderant amounts of acid components other than silica, the most frequent of these being Fe_2O_3 and TiO_2, we may distinguish the relative proportions of these in Suborders. They occur in those parts of the system where minerals of the M subgroup preponderate.

Rang.— Having thus recognized the acid components, with the exception of the radicals Cl and SO_3, which can only be present to a subordinate extent, we have now to take up the recognition and expression of the bases in the magma. Consequently, Rangs are formed on the chemical characters of the bases in the minerals of the preponderant salic or femic group, according to the Class under consideration. And since there are several of these bases generally present it is necessary to treat them in successive groups. The first and most general division constitutes Rangs.

Subrang.—The comparison of those bases which are united to form the groups of bases recognized in forming Rangs constitutes Subrangs.

Grad.—The characters of the subordinate mineral group, femic or salic, will be treated in a manner analogous to that employed when considering the preponderant, salic or femic, group, the only difference being that as the group under consideration is subordinate fewer distinctions will be needed.

Grads will be based on the general acidic proportions in the minerals of the subordinate group, and will follow the plan of the divisions for Order in the preponderant group.

Subgrad.—These divisions will follow the lines of the subdivisions for Rang and Subrang, and will express the general and special chemical characters of the bases of the minerals of the subordinate mineral group.

Sections.—The application of the above principles shows, however, that in certain points more numerous subdivisions are needed. This necessity is met by the formation of *Sections* of any of the divisions above described. These Sections will be based on more special characters according to circumstances. No general rule can be laid down for them, but they will be explained in their respective places in the subsequent description of the various divisions.

Family and Series.—The grouping of rocks proposed in this system of classification is for the purpose of bringing together rocks that are alike chemically, and also mineralogically and texturally. There is need, however, in the broader treatment of igneous rocks, especially with reference to their genetic relations and to their occurrence in petrographic provinces, to group them in other ways. For these purposes the terms *Family* and *Series* are appropriate, and it is proposed that they be used as follows:

The term *Family* may be applied to a group of rocks that have been developed genetically from a common magma by processes of differentiation. In its broadest sense it may be applied to all the rocks of a petrographic province. But it is evident that there may be genetic groups of several degrees of consanguinity, for which more specific designations will be necessary. It is suggested that for these groups terms analogous to Family be used.

The term *Series* may be used, in an extension of Brögger's sense,[1] for groups of rocks characterized by similar ratios of certain constituents, as alkalies, but with varying amounts of other constituents, as silica. These series will be of very different characters dependent on the petrographic province, and will have no place in the system proper, since they will traverse it in all directions. They may be designated, as at present, by the use of the names of the extremes, with or without that of an intermediate member.

CLASSES.—It is proposed to divide igneous rocks into five Classes, according to the calculated proportions of the standard mineral groups above defined. As previously stated, these groups are designated as *sal* and *fem* in formulæ, and the descriptive adjectives derived from these are given below.

Class I: $\frac{\text{sal}}{\text{fem}} > \frac{7}{1}$, persalic.

This Class contains rocks *extremely* rich in the salic minerals —quartz, feldspars, feldspathoids, and corundum.

Class II: $\frac{\text{sal}}{\text{fem}} < \frac{7}{1} > \frac{5}{3}$, dosalic.

In the rocks of this Class the salic minerals are *dominant* and the femic minerals *subordinate.*

Class III: $\frac{\text{sal}}{\text{fem}} < \frac{5}{3} > \frac{3}{5}$, salfemic.

In this Class fall the rocks in which the salic and femic minerals are *equal or nearly equal* in amount.

Class IV: $\frac{\text{sal}}{\text{fem}} < \frac{3}{5} > \frac{1}{7}$, dofemic.

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[1] *Die Eruptivgesteine des Kristianiagebietes,* Vol. I (1894), p. 169.

The femic minerals are here *dominant* and those of the salic group *subordinate*.

$$\textit{Class V:}\ \frac{\text{sal}}{\text{fem}} < \frac{1}{7}\text{, perfemic.}$$

The rocks of this Class are extremely rich in the femic minerals—pyroxenes, olivine, magnetite, etc.

SUBCLASSES.—The next step in the systematic subdivision takes account of the distinctions among the standard minerals constituting the salic and femic groups. There being a considerable number of these minerals in each group, it is necessary for reasons already given to divide each group into two parts. Of the salic minerals, quartz, feldspar and the feldspathoids form a closely associated series when considered petrographically and chemically, and may be contrasted with corundum, zircon or other salic minerals. Group I, therefore, falls into Part 1, quartz, feldspars and feldspathoids, indicated in certain abbreviated expressions by the letters Q, F and L, and into Part 2, corundum, zircon, etc., indicated respectively by C and Z.

Group I.
- Part 1. *Quartz* (Q), *Feldspars* (orthoclase, albite and anorthite) (F). *Feldspathoids* (leucite, nephelite, sodalite, noselite) (L).
- Part 2. *Corundum* (C) and *Zircon* (Z).

Similarly, of the femic minerals, the pyroxenes, olivine, akermanite, magnetite, ilmenite and titanite are closely associated in rocks, and form frequent transitional series of rocks with different proportions of these minerals. They may be grouped together as Part 1 of Group II, and contrasted with apatite, fluorite, pyrite, the metals and other femic minerals constituting Part 2. In abbreviated expressions minerals of Part 1 are indicated by the letters P, O and M, those of Part 2 collectively by A.

Group II.
- Part 1. *Pyroxenes* (diopside, hypersthene, wollastonite and acmite) (P). *Olivine* and *akermanite* (O). *Magnetite*, *hematite*, *ilmenite*, *rutile*, *perofskite* and *titanite* (M).
- Part 2. *Apatite*, *fluorite*, *pyrite*, etc. (A).

Subclasses in Classes I, II and III are made on a fivefold basis by considering the relative proportions of the two parts of the salic group, just described. The reasons for using the salic minerals in Class III, instead of the femic, are given in the discussion of Orders. In Classes IV and V Subclasses are formed on the proportions of the two parts of the femic group.

In Classes I, II and III the divisions will be as follows:

Subclass 1: $\frac{QFL}{CZ} > \frac{7}{1}$.

Subclass 2: $\frac{QFL}{CZ} < \frac{7}{1} > \frac{5}{3}$.

Subclass 3: $\frac{QFL}{CZ} < \frac{5}{3} > \frac{3}{5}$.

Subclass 4: $\frac{QFL}{CZ} < \frac{3}{5} > \frac{1}{7}$.

Subclass 5: $\frac{QFL}{CZ} < \frac{1}{7}$.

In Classes IV and V the divisions will be:

Subclass 1: $\frac{POM}{A} > \frac{7}{1}$.

Subclass 2: $\frac{POM}{A} < \frac{7}{1} > \frac{5}{3}$.

Subclass 3: $\frac{POM}{A} < \frac{5}{3} > \frac{3}{5}$.

Subclass 4: $\frac{POM}{A} < \frac{3}{5} > \frac{1}{7}$.

Subclass 5: $\frac{POM}{A} < \frac{1}{7}$.

In the first three classes the distinctions between corundum and zircon may be made in those subclasses in which they are present in notable amount, by the formation of *Sections* as follows:

Section 1: $\frac{C}{Z} > \frac{7}{1}$,

Section 2: $\frac{C}{Z} < \frac{7}{1} > \frac{5}{3}$, Section 3: $\frac{C}{Z} < \frac{5}{3} > \frac{3}{5}$.

Section 4: $\frac{C}{Z} < \frac{3}{5} > \frac{1}{7}$.

Section 5: $\frac{C}{Z} < \frac{1}{7}$.

In Classes IV and V, Sections may be made analogously, when it is necessary to recognize distinctions between notable amounts of apatite and various metals and sulphides. They need not be given here as the principles controlling them are the same as above.

It will be noted that the vast majority of igneous rocks of all Classes belong to the first Subclass in each Class. There are few rocks known belonging to most of the Subclasses here proposed, but if ever found their classification is thus provided for and will not disturb that of the rocks already known.

In the remainder of this article the classification set forth pertains to Subclasses I of each of the five Classes, unless otherwise stated.

ORDERS.—The division of Subclasses to form *Orders* is made on a basis of the relative proportions of the standard minerals in the preponderant group.

For Classes I and II the preponderant minerals are salic; and in Class III salic minerals are considered before femic, and since minerals of Part 1 are preponderant over those of Part 2 the former are made the basis of subdivision, which is as follows:

a) Quartz, Q.

b) Feldspars (orthoclase, albite, anorthite), F.

c) Feldspathoids (lenads) (leucite, nephelite, sodalite and noselite), L.

Owing to the fact, already discussed, that quartz and the feldspathoids (lenads) are in almost all cases antithetical, so that they do not occur together, these three factors may be employed serially and in the first three Subclasses of Classes I, II and

III the Orders are formed by a double application of the plan of fivefold division, resulting in nine Orders.

Owing to the cumbersomeness of the phrases necessary to describe Orders when the mineralogical group-names are employed quantitatively, it is advisable to use abbreviated terms mnemonic of these mineralogical groups. For these we suggest the following syllables: *quar*, mnemonic of quartz; *fel*, mnemonic of feldspar; *len*, mnemonic of leucite and nephelite, which is understood to include the other standard feldspathoids, sodalite and noselite. From these syllables, with the addition of the proper quantitative prefixes already mentioned, are formed adjectives descriptive of the several Orders as given below.

On account of the resemblance between the words feldspar and feldspathoid, in such frequent use, we suggest for the latter the term *lenad*.

Order 1:	$\frac{Q}{F} > \frac{7}{1}$,	quartz extreme,	perquaric.
Order 2:	$\frac{Q}{F} < \frac{7}{1} > \frac{5}{3}$,	quartz dominant,	doquaric.
Order 3:	$\frac{Q}{F} < \frac{5}{3} > \frac{3}{3}$,	quartz and feldspar equal,	quarfelic.
Order 4:	$\frac{Q}{F} < \frac{3}{5} > \frac{1}{7}$,	feldspar dominant over quartz,	quardofelic.
Order 5:	$\frac{Q \text{ or } L}{F} < \frac{1}{7}$,	feldspar extreme,	perfelic.
Order 6:	$\frac{L}{F} < \frac{3}{5} > \frac{1}{7}$,	feldspar dominant over lenad,	lendofelic.
Order 7:	$\frac{L}{F} < \frac{5}{3} > \frac{3}{5}$,	feldspar and lenad equal,	lenfelic.
Order 8:	$\frac{L}{F} < \frac{7}{1} > \frac{5}{3}$,	lenad dominant,	dolenic.
Order 9:	$\frac{L}{F} > \frac{7}{1}$,	lenad extreme,	perlenic.

It will be noted that in Class III, in which the salic and femic minerals are present in equal or nearly equal proportions, *Orders* are established as though the salic minerals were preponderant. This has been done for the reason that both groups of minerals being present in nearly equal amounts, it is necessary to select one group arbitrarily for the basis of division to form *Orders*. Preference is given to the salic group because the greater number of rocks belonging to this class, so far as known, contain slightly more salic minerals than femic, within the range of $\frac{5}{3}$ and $\frac{3}{5}$, Moreover, the present custom of classifying these rocks primarily on a basis of the feldspathic constituents may be allowed to influence the choice. The division of Class III to form *Orders* is therefore the same as those in Classes I and II.

For Classes IV and V the dominant minerals are femic, and the division to form Orders must be based on the relative proportions of minerals of the first Part of this group. They may be grouped into silicates, 1, and non-silicates with titanosilicates, 2. The silicates are further divided into *a*) metasilicates, and *b*) lower silicates, as follows:

1 { *a*) Pyroxenes, diopside, wollastonite, hypersthene, and acmite, P.
   b) Olivine and akermanite, O.
2 Magnetite, hematite, ilmenite, titanite, etc., M.

Orders in these Classes are formed by comparing subgroups 1 and 2, the silicates and non-silicates. For adjectives to describe these Orders we suggest the following syllables mnemonic of the subgroups of femic minerals: *pol*, to indicate pyroxene and olivine with akermanite; *mit*, to indicate magnetite, ilmanite, titantite and the other minerals of this subgroup. For adjectives to describe Sections of Orders, based on a comparison of the two parts of the silicate subgroup we suggest the syllables: *pyr*, denoting the pyroxenes, and *ol*, denoting olivine and akermanite.

Order 1:	$\frac{P+O}{M} > \frac{7}{1}$,	femic silicate extreme,	perpolic.
Order 2:	$\frac{P+O}{M} < \frac{7}{1} > \frac{5}{3}$,	femic silicate dominant,	dopolic.
Order 3:	$\frac{P+O}{M} < \frac{5}{3} > \frac{3}{5}$,	femic silicate and non-silicate equal,	polmitic.

Order 4: $\frac{P+O}{M} < \frac{3}{5} > \frac{1}{7}$, femic non-silicate dominant. domitic,

Order 5: $\frac{P+O}{M} < \frac{1}{7}$, femic non-silicate extreme. permitic.

Sections of Orders.—The division of Orders into Sections is needed in Classes IV and V, to express the relative proportions of the subgroups of the preponderant mineral groups, that is, the proportions between the pyroxene and olivine subgroups.

In Orders 1, 2, and 3 of Classes IV and V, where the polic minerals are extreme, or dominate over, or are equal to the mitic, this division is carried out on a fivefold basis and results as follows :

Section 1: $\frac{P}{O} > \frac{7}{1}$, pyroxene extreme. perpyric,

Section 2: $\frac{P}{O} < \frac{7}{1} > \frac{5}{3}$, pyroxene dominant. dopyric.

Section 3: $\frac{P}{O} < \frac{5}{3} > \frac{3}{5}$, pyroxene and olivine equal. pyrolic.

Section 4: $\frac{P}{O} < \frac{3}{5} > \frac{1}{7}$, olivine dominant. domolic.

Section 5: $\frac{P}{O} < \frac{1}{7}$, olivine extreme. perolic.

SUBORDERS.—In Orders 4 and 5 of Classes IV and V the non-silicate, mitic, minerals preponderate. The subgroups of these minerals, in greatest abundance and most characteristic of rocks belonging to these Orders, contain Fe_2O_3 and TiO_2. The first subgroup includes magnetite and hematite, and is indicated by the symbol H. The second subgroup includes ilmenite, titanite, perofskite and rutile, and is indicated by T. For these subgroups we suggest the syllables *hem* and *til*, mnemonic of the minerals composing then. The relative proportions of these minerals are recognized in Suborders on a fivefold basis, as follows :

Suborder 1: $\frac{H}{T} > \frac{7}{1}$, perhemic.

Suborder 2: $\frac{H}{T} < \frac{7}{1} > \frac{5}{3}$, dohemic.

Suborder 3: $\frac{H}{T} < \frac{5}{3} > \frac{3}{5}$, tilhemic.

Suborder 4: $\frac{H}{T} < \frac{3}{5} > \frac{1}{7}$, dotilic.

Suborder 5: $\frac{H}{T} < \frac{1}{7}$, pertilic.

RANG.—The division for *Rang* is based on the general chemical character of the bases in the minerals of the preponderant group in each *Class*, that is, in the salic or femic minerals used for the formation of *Orders*.

For salic minerals this is expressed by the terms *alkalic* and *calcic*, which relate to the feldspars and lenads. Divisions are based on the proportions of molecules of $K_2O' +$ Na_2O', to CaO' in these minerals, K_2O', Na_2O' and CaO' being the parts of these rock components allotted to salic minerals. The divisions in Classes I, II and III are fivefold:

Rang 1: $\frac{K_2O' + Na_2O'}{CaO'} > \frac{7}{1}$, peralkalic.

Rang 2: $\frac{K_2O' + Na_2O'}{CaO'} < \frac{7}{1} > \frac{5}{3}$, domalkalic.

Rang 3: $\frac{K_2O' + Na_2O'}{CaO'} < \frac{5}{3} > \frac{3}{5}$, alkalicalcic.

Rang 4: $\frac{K_2O' + Na_2O'}{CaO'} < \frac{3}{5} > \frac{1}{7}$, docalcic.

Rang 5: $\frac{K_2O' + Na_2O'}{CaO'} < \frac{1}{7}$, percalcic.

In Order 6, where feldspar is dominant over the lenads, only the first four Rangs will occur, in Order 7 only the first three, in Order 8 only the first two, and in Order 9 only the first one.

For femic minerals the general chemical characters of the bases are commonly expressed by the terms *ferromagnesian*, *calcic*, and *alkalic*. But three independent factors are not to be employed in this system at one time, and it is necessary to combine two of the three to form a dual basis for a first subdivision. This is accomplished by uniting the first two and comparing the proportions of MgO, FeO, CaO″, and the *alkalies*, K_2O'', Na_2O''. In this case CaO″, K_2O'' and Na_2O'', are the parts of these rock components allotted to femic minerals. For the adjective expressing the first named quality, corresponding to *alkalic*, we propose to use the word *mirlic*, referring to the *m*agnesium, *ir*on and *l*ime. Upon a fivefold basis of comparison of these two sets of chemical constituents we form Rangs of Classes IV and V, although the more alkalic Rangs here provided are not yet known. They are:

$$\text{Rang 1: } \frac{(\text{Mg, Fe})\text{O} + \text{CaO}''}{\text{K}_2\text{O}'' + \text{Na}_2\text{O}''} > \frac{7}{1}, \quad \text{permirlic.}$$

$$\text{Rang 2: } \frac{(\text{Mg, Fe})\text{O} + \text{CaO}''}{\text{K}_2\text{O}'' + \text{Na}_2\text{O}''} < \frac{7}{1} > \frac{5}{3}, \quad \text{domirlic.}$$

$$\text{Rang 3: } \frac{(\text{Mg, Fe})\text{O} + \text{CaO}''}{\text{K}_2\text{O}'' + \text{Na}_2\text{O}''} < \frac{5}{3} > \frac{3}{5}, \quad \text{alkalimirlic.}$$

$$\text{Rang 4: } \frac{(\text{Mg, Fe})\text{O} + \text{CaO}''}{\text{K}_2\text{O}'' + \text{Na}_2\text{O}''} < \frac{3}{5} > \frac{1}{7}, \quad \text{domalkalic.}$$

$$\text{Rang 5: } \frac{(\text{Mg, Fe})\text{O} + \text{CaO}''}{\text{K}_2\text{O}'' + \text{Na}_2\text{O}''} < \frac{1}{7}, \quad \text{peralkalic.}$$

Sections of Rangs in Classes IV and V are necessary to recognize the varying proportions between the *ferromagnesian* and *calcic* characters of femic minerals, since the magnesium and iron are so closely associated chemically and characterize certain femic minerals free from calcium. For the word ferromagnesian, which is used in a somewhat loose manner in petrography, we propose to introduce the word, *miric*, to indicate strictly the *m*agnesium and *ir*on content in femic minerals, and to be mnemonic of these two metals.

These Sections of Rangs in Classes IV and V have been made on a fivefold basis as follows:

$$\text{Section 1: } \frac{(\text{Mg, Fe})\text{O}}{\text{CaO}''} > \frac{7}{1}, \quad \text{permiric.}$$

Section 2: $\frac{(Mg, Fe)O}{CaO''} < \frac{7}{1} > \frac{5}{3}$, domiric.

Section 3: $\frac{(Mg, Fe)O}{CaO''} < \frac{5}{3} > \frac{3}{5}$, calcimiric.

Section 4: $\frac{(Mg, Fe)O}{CaO''} < \frac{3}{5} > \frac{1}{7}$, docalcic.

Section 5: $\frac{(Mg, Fe)O}{CaO''} < \frac{1}{7}$, percalcic.

SUBRANG.—Subrangs are made on a basis of the special character of the variable or compounded chemical quality used in forming *Rang*. In Classes I, II and III this variable quality is in the ratio of alkalies, potash and soda, and the following subdivisions are recognized for Rangs I, II and III.

Subrang 1: $\frac{K_2O'}{Na_2O'} > \frac{7}{1}$, perpotassic.

Subrang 2: $\frac{K_2O'}{Na_2O'} < \frac{7}{1} > \frac{5}{3}$, dopotassic.

Subrang 3: $\frac{K_2O'}{Na_2O'} < \frac{5}{3} > \frac{3}{5}$, sodipotassic.

Subrang 4: $\frac{K_2O'}{Na_2O'} < \frac{3}{5} > \frac{1}{7}$, dosodic.

Subrang 5: $\frac{K_2O'}{Na_2O'} < \frac{1}{7}$, persodic.

In Rangs IV and V of Classes I, II and III only three divisions are used because of the subordinate amount of alkalies. These Subrangs are:

Subrang 1: $\frac{K_2O'}{Na_2O'} > \frac{5}{3}$, prepotassic.

Subrang 2: $\frac{K_2O'}{Na_2O'} < \frac{5}{3} > \frac{3}{5}$, sodipotassic.

Subrang 3: $\frac{K_2O'}{Na_2O'} < \frac{3}{5}$, presodic.

In Classes IV and V the variable quality is in the miric content. The alkalies are so preponderantly sodic that they do not require subdivision, and no distinction on a basis of the relative amounts of soda and potash are needed. For the present at least when femic minerals are said to be alkalic, it may be assumed that they are *presodic.* The divisions in Sections 1 and 2 of Rangs I and II are:

Subrang 1: $\frac{MgO}{FeO} > \frac{7}{1}$, permagnesic.

Subrang 2: $\frac{MgO}{FeO} < \frac{7}{1} > \frac{5}{3}$, domagnesic.

Subrang 3: $\frac{MgO}{FeO} < \frac{5}{3} > \frac{3}{5}$, magnesiferrous.

Subrang 4: $\frac{MgO}{FeO} < \frac{3}{5} > \frac{1}{7}$, doferrous.

Subrang 5: $\frac{MgO}{FeO} < \frac{1}{7}$, perferrous.

In Sections 3 of Rangs I and II and in other Rangs of Classes IV and V only *three* divisions are used, because of the subordinate amount of miric component. These are:

Subrang 1: $\frac{MgO}{FeO} > \frac{5}{3}$, premagnesic.

Subrang 2: $\frac{MgO}{FeO} < \frac{5}{3} > \frac{3}{5}$, magnesiferrous.

Subrang 3: $\frac{MgO}{FeO} < \frac{3}{5}$, preferrous.

Sections of Subrangs.—In certain Subrangs a division into Sections is necessary on account of the presence of various acid radicals or for other reasons.

In Classes I, II and III the salic mineral groups, quartz, feldspar and lenads, may be considered as: (*a*) silica and simple silicates, and (*b*) silicates combined with some other salt, or silicates containing some other acid, as Cl and SO_3. The latter are confined wholly to the lenads. This distinction is advisable here, rather than at Suborders, where it might otherwise fall, because of the great change in the mineralogical character of the lenad group induced by the presence of very small amounts of Cl and SO_3 (often less than 1 per cent.

of Cl yielding a notable amount of sodalite), and because, so far as has been observed, or seems *a priori* possible, the minerals of the sodalite group are only present in the sodic or sodipotassic Subrangs of Classes I, II and III. It may be pointed out that the sodalite minerals are also characterized by the presence of more Na_2O than Al_2O_3.

The lenads to be contrasted are the simple silicates, nephelite and leucite, on the one hand, and the more complex silicates, sodalite and noselite, on the other. The former may be designated by the symbols *ne* and *lc*, and the latter by *so* and *no*, and the mnemonic syallables indicating these subgroups are *nel* and *son*.

The division will be needed only in Orders 6, 7, 8 and 9, which contain notable amounts of lenads, and will be fivefold in the sodipotassic, dosodic and persodic Subrangs of the peralkalic, domalkalic and alkalicalcic Rangs.

Section 1: $\frac{\text{ne, lc}}{\text{so, no}} < \frac{7}{1}$, pernelic.

Section 2: $\frac{\text{ne, lc}}{\text{so, no}} < \frac{7}{1} > \frac{5}{3}$, donelic.

Section 3: $\frac{\text{ne, lc}}{\text{so, no}} < \frac{5}{3} > \frac{3}{5}$, sonnelic.

Section 4: $\frac{\text{ne, lc}}{\text{so, no}} < \frac{3}{5} > \frac{1}{7}$, dosonic.

Section 5: $\frac{\text{ne, lc}}{\text{so, no}} < \frac{1}{7}$, personic.

In the dopotassic Subrangs of the Rangs just mentioned, and in the sodipotassic and presodic Subrangs of the docalcic Rangs, the division will be threefold:

Section 1: $\frac{\text{ne, lc}}{\text{so, no}} > \frac{5}{3}$, prenelic.

Section 2: $\frac{\text{lc, ne}}{\text{so, no}} < \frac{5}{3} > \frac{3}{5}$, sonnelic.

Section 3: $\frac{\text{ne, lc}}{\text{so, no}} < \frac{3}{5}$, presonic.

Since we have to deal here with the two acid radicals Cl and SO_3, we may distinguish between the sodalite and noselite rocks by dividing Sections 3, 4 and 5 of the fivefold division above, and Sections 2 and 3 of the threefold, on a threefold basis, which appears to be a sufficient subdivision. These Subsections will be as follows:

Subsection 1: $\frac{Cl}{SO_3} > \frac{5}{3}$, prechloric.

Subsection 2: $\frac{Cl}{SO_3} < \frac{5}{3} > \frac{3}{5}$, chlorsulphic.

Subsection 3: $\frac{Cl}{SO_3} < \frac{3}{5}$. presulphic.

Rocks belonging to each of the five Classes here proposed have been fully characterized mineralogically and chemically, as far as the preponderant salic and femic groups of minerals are concerned. There remains the consideration of the subordinate group, femic or salic, in each case, in order to complete the chemico-mineralogical classification of the rocks.

In Classes I and V since the preponderant group is present in extreme amount, the subordinate group is negligible, and no further division is necessary.

In Class II the subordinate group is present in notable amount, and is femic, while in Class III the femic group is given second place, after salic, so that in both cases we have to do with femic minerals, and further division will take place in this group and will be in general along the lines laid down in the preceding pages in the description of the divisions from Order to Subrang in Classes IV and V.

In Class IV the subordinate group is salic and is present in notable amount, so that further division will take place in this group, following the lines of division from Order to Subrang in Classes I, II and III.

It will furthermore be seen that, since in Classes II and IV the subordinate femic and salic minerals respectively are not equal to the preponderant salic and femic, it will not be necessary in these Classes to make the divisions, at least for the present, more than threefold, nor will it be useful to make in all cases the finer distinctions which obtain in the divisions based on the preponderant group of minerals.

In Class III, on the other hand, where the femic minerals are equal to the salic, and may in fact exceed them in some cases, the fivefold subdivision will be employed, and, as far as possible, the distinctions made in the first divisions of Classes IV and V will be recognized.

It may be noted here that it appears that in actual practice these later divisions will be used comparatively seldom in Classes II and IV, and it will be remembered that they do not exist in Classes I and V, but that they become important in the intermediate Class III.

Grads are based on the proportions of the standard minerals of the subordinate femic and salic groups in Classes II and IV and of the femic group in Class III.

For Class II they are:

Grad 1:	$\frac{P+O}{M} > \frac{5}{3}$,	femic silicate predominant,	prepolic.
Grad 2:	$\frac{P+O}{M} < \frac{5}{3} > \frac{3}{5}$,	femic silicate and non-silicate equal	polmitic.
Grad 3:	$\frac{P+O}{M} < \frac{3}{5}$,	femic non-silicate predominant,	premitic.

In Class III they are:

Grad 1:	$\frac{P+O}{M} > \frac{7}{1}$,	femic silicate extreme,	perpolic.
Grad 2:	$\frac{P+O}{M} < \frac{7}{1} > \frac{5}{3}$,	femic silicate dominant,	dopolic.
Grad 3:	$\frac{P+O}{M} < \frac{5}{3} > \frac{3}{5}$,	femic silicate and non-silicate equal	polmitic.
Grad 4:	$\frac{P+O}{M} < \frac{3}{5} > \frac{1}{7}$,	femic non-silicate dominant,	domitic.
Grad 5:	$\frac{P+O}{M} < \frac{1}{7}$,	femic non-silicate extreme,	permitic.

In Class III it is also necessary to discriminate further between pyroxene and olivine, corresponding to the Suborders of Orders 1, 2 and 3 of Classes IV and V. This will be necessary only in Grads 1, 2 and 3 of Class III. They are:

Section 1:	$\frac{P}{O} > \frac{5}{3}$,	pyroxene predominant,	prepyric.
Section 2:	$\frac{P}{O} < \frac{5}{3} > \frac{3}{5}$,	pyroxene and olivine equal,	pyrolic
Section 3:	$\frac{P}{O} < \frac{3}{5}$,	olivine predominant	preolic.

In Class IV the subordinate minerals belong to the salic group. Their division into Grads is of the same kind as that forming Orders in Classes I, II and III, but since their amount is considerably smaller than in rocks of these Classes, the division is on a threefold basis, resulting in five Grads, as follows:

Grad 1:	$\frac{Q}{F} > \frac{5}{3}$,	quartz predominant,	prequaric.
Grad 2:	$\frac{Q}{F} < \frac{5}{3} > \frac{3}{5}$,	quartz and feldspar equal,	quarfelic.
Grad 3:	$\frac{Q \text{ or } L}{F} < \frac{3}{5}$,	feldspar predominant,	prefelic.
Grad 4:	$\frac{L}{F} < \frac{5}{3} > \frac{3}{5}$,	feldspar and lenads equal,	lenfelic.
Grad 5:	$\frac{L}{F} > \frac{5}{3}$,	lenads predominant,	prelenic.

SUBGRADS are formed on the general chemical character of the bases of the minerals employed to form Grads, and bear the same relation to the latter that Rangs bear to Orders. On account of the smaller amount of the minerals involved in Classes II and IV it is not thought desirable to give the distinctions as great a taxonomic value as when the preponderant minerals are concerned, and so they are made the basis of Subgrads rather than of a new taxonomic division.

In Class II the subordinate minerals being femic the chemical divisions are similar to those forming Rangs in Classes IV and V, but are on a threefold basis because of the smaller amount of femic minerals, as follows:

Subgrad 1: $\frac{(Mg, Fe)O + CaO''}{K_2O'' + Na_2O''} > \frac{5}{3}$, premirlic.

Subgrad 2: $\frac{(Mg, Fe)O + CaO''}{K_2O'' + Na_2O''} < \frac{5}{3} > \frac{3}{5}$, alkalimirlic.

Subgrad 3: $\frac{(Mg, Fe)O + CaO''}{K_2O'' + Na_2O''} < \frac{3}{5}$, prealkalic.

In Class III Subgrads are formed on a basis of the chemical characters of the femic minerals by analogy with those of Class II, but because of the greater proportions of these minerals the division is on a fivefold basis, yielding:

Subgrad 1: $\frac{(Mg, Fe)O + CaO''}{K_2O'' + Na_2O''} > \frac{7}{1}$, permirlic.

Subgrad 2: $\frac{(Mg, Fe)O + CaO''}{K_2O'' + Na_2O''} < \frac{7}{1} > \frac{5}{3}$, domirlic.

Subgrad 3: $\frac{(Mg, Fe)O + CaO''}{K_2O'' + Na_2O''} < \frac{5}{3} > \frac{3}{5}$, alkalimirlic.

Subgrad 4: $\frac{(Mg, Fe)O + CaO''}{K_2O'' + Na_2O''} < \frac{3}{5} > \frac{1}{7}$, domalkalic.

Subgrad 5: $\frac{(Mg, Fe)O + CaO''}{K_2O'' + Na_2O''} < \frac{1}{7}$, peralkalic.

In Class IV the minerals forming Grads are salic, and since they are subordinate to the femic it is advisable to make only three divisions instead of five, as follows:

Subgrad 1: $\frac{K_2O' + Na_2O'}{CaO'} > \frac{5}{3}$, prealkalic.

Subgrad 2: $\frac{K_2O' + Na_2O'}{CaO'} < \frac{5}{3} > \frac{3}{5}$, alkalicalcic.

Subgrad 3: $\frac{K_2O' + Na_2O'}{CaO'} < \frac{3}{5}$, precalcic.

Sections of Subgrads in Class III are established because the amount of femic minerals is equal or nearly equal to that of the salic, and it is desirable to make further chemical distinctions as in the case of Sections of Rangs in Classes IV and V. The divisions are the same in both cases, and are based on the proportions of miric and calcic constituents. They need only be used in Rangs 1, 2, and 3.

Section 1: $\frac{(\mathrm{Mg, Fe})\mathrm{O}}{\mathrm{CaO}''} > \frac{5}{3}$, premiric.

Section 2: $\frac{(\mathrm{Mg, Fe})\mathrm{O}}{\mathrm{CaO}''} < \frac{5}{3} > \frac{3}{5}$, calcimiric.

Section 3: $\frac{(\mathrm{Mg, Fe})\mathrm{O}}{\mathrm{CaO}''} > \frac{3}{5}$, precalcic.

Subsections of Sections 1 and 2 are based on the proportions of magnesic and ferrous components as in the case of Subrangs in Classes IV and V. They are:

Subsection 1: $\frac{\mathrm{MgO}}{\mathrm{FeO}} > \frac{5}{3}$, premagnesic.

Subsection 2: $\frac{\mathrm{MgO}}{\mathrm{FeO}} < \frac{5}{3} > \frac{3}{5}$, magnesiferrous.

Subsection 3: $\frac{\mathrm{MgO}}{\mathrm{FeO}} < \frac{3}{5}$, preferrous.

It is understood, of course, that all the divisions just described are not needed, as has been explained in regard to those based on the preponderant group of minerals. Thus a calcic Subgrad is not needed in a Grad with dominant lenads. In such cases it is simply inactive.

THE RÔLE OF ACTUAL MINERAL DEVELOPMENT AND TEXTURE IN ROCK CLASSIFICATION.

The methods employed in forming *Classes*, *Orders*, *Rangs*, *Grads*, and their subdivisions are distinctly chemico-mineralogical and chemical, the minerals considered being those defined as *standard*. These divisions are applicable to magmas regardless of their mode of solidification or crystallization. The classification so far is purely magmatic.

The chief object attained up to this point by the system proposed is the uniting of all igneous rocks having like chemical compositions into divisions or groups which conform to our present conceptions of chemical petrographical unity. And it has been our endeavor at the same time to prepare such a scheme of subdivision that should demands be made for greater chemical discrimination by future petrographers, further subdivision may be carried on as an elaboration of the classification here suggested.

But the problem before us being the classification of igneous rocks, there remains the method of treatment of the rocks themselves. This involves the consideration of the minerals actually present, including the aluminous ferromagnesian minerals, which occur in the great majority of igneous rocks and often form the preponderant constituents. It also involves the consideration of the texture of the rock, which is perhaps the most obvious feature, as well as the legend of its physical history. The elimination of the aluminous ferromagnesian minerals from the system of magmatic classification just described is frankly for its simplification. The exact expression of the chemical magmatic units which would be required should these minerals be introduced would be so intricate as to be practically useless. It is conceivable that an exact mathematical expression involving all of the variable factors or interchangeable combinations, such as are represented by the compositions of biotites, amphiboles, and augites, is possible, but it would be beyond the reach of petrographers generally.

The actual mineral development of an igneous rock is to a great extent so related to the texture that the two are interdependent, which naturally follows from their both being controlled to a large degree by the physical conditions attending eruption and solidification. But since these relations as well as the physical conditions are far from simple, it is therefore necessary, for the present at least, to treat the mineral and textural development of igneous rocks separately.

In petrographical classifications in present use either the actual composition or the texture is made the basis of subdivision, and the other is used for further subdivision. And it is recognized that there is variation in either case within the limits of petrographical divisions, however constituted.

This may be illustrated by the following examples:

1. Let us consider the case of somewhat similar rocks having like textures but somewhat different mineral compositions which have been classed together under one name on a basis of texture, and subsequently separated on a basis of mineral differences, the gabbros. Among several of these rocks with phanerocrystalline granular texture there are those with hornblende, or mica, or olivine, and they are known as hornblende-gabbro, mica-gabbro, and olivine-gabbro.

2. There is a case of a number of rocks having nearly the same mineral composition (labradorite, augite, olivine, and magnetite) and called basalt, which possess quite different textures, such as evenly granular, ophitic, intersertal, porphyritic, or microlitic glassy.

We can see strong grounds for both of these methods of classification, and each may serve an important purpose in petrographical work. There are instances in which one method of correlation is more valuable than another. Freedom of choice should be allowed if consistent with definiteness and stability of the system of classification.

For these reasons the variable characters of each petrographical unit established by the system of classification we propose, which characters are results of the conditions attending solidification, or crystallization, are treated in a different manner from the chemical characters. They are treated as variable factors in the system, although inherent and persistent qualities of a particular rock. They are assigned the rôle of qualifiers of the magmatic units wherever there is need of further subdivision. They consequently appear in the production of a systematic nomenclature, which is an integral part of comprehensive classification.

Actual Mineral Composition.

Let us first consider what minerals may actually be developed in rocks and what relations they bear to the standard minerals which are used to express the chemical composition of a magma unit. And let us assume that the rock is holocrystalline. Those cases in which more or less of the magma becomes glass will be discussed afterward.

For convenience we introduce two terms which have suggested themselves as substitutes for the cumbrous and oft-repeated expressions, *standard mineral composition* (that calculated from the rock analysis) and *actual mineral composition*. For the first we propose the word *norm*[1], and for the second the word *mode*.[2] The standard minerals which make up the norm are to be called the *normative*[3] minerals, not the *normal* ones, since the latter adjective has the meaning of usual or common.

The questions arise, how far does the *mode* of a holocrystalline rock correspond to the *norm*, and what distinctions are necessary among rocks belonging to one magma unit because of differences among them due to their actual mineral composition?

There are all possible grades of correspondence between the mode and norm of rocks when the whole range of rocks is taken into account, but when this inquiry is applied to separate magmatic units the answer must be modified according to the kind of magma considered.

For example, some magmas of extremely simple composition crystallize in one manner only, so far as our present knowledge goes. Those composed of almost pure silica form only quartz with negligible amounts of other things. Magmas whose norm is quartz and orthoclase will form rocks with these minerals as the *mode*. Magmas whose norm is a simple rock-making mineral, as labradorite or olivine, will crystallize into rocks composed of one of these minerals only.

Consequently rocks belonging to magmatic divisions characterized by extreme amounts of standard quartz, orthoclase, albite or nephelite; of the lime-soda-feldspars; of diopside or hypersthene, or olivine, or magnetite, will have actual mineral compositions very closely corresponding to the calculated norm. That is, the preponderant minerals actually crystallized will be the same as those calculated from the rock analysis. Variations may occur in the kind of subordinate minerals for reasons which will be explained presently.

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[1] A rule, pattern, model, authoritative standard.—*Century Dictionary*.

[2] The natural disposition or manner of existence of anything.—*Ibid*.

[3] Establishing or setting up a norm.—*Ibid*.

On the other hand, magmas containing nearly equal amounts of both salic and femic molecules or dominant amounts of the latter may develop alferric (aluminous ferromagnesian) minerals to such an extent as to prevent the crystallization of any appreciable amount of the standard minerals. A well-known example of this is the hornblendite of Brandberg, in Gran, Norway,[1] a rock of Class III, which crystallized as almost pure hornblende.

A similar magma, however, may crystallize into minerals corresponding closely to the norm, as in the case of the nephelite-basanite of Colfax county, New Mexico.

It follows from this that in some divisions of the system the actual mineral composition of holocrystalline rocks will accord very closely with their norms, while in others it may or may not. And in these cases there may be various degrees of correspondence between the mode and norm.

In general a number of degrees of correspondence between the actual and the standard mineral composition of igneous rocks may be recognized. They may be expressed as follows:

1. COMPLETE OR ALMOST COMPLETE ACCORD BETWEEN THE MODE AND NORM.— In the first case the two correspond exactly both qualitatively and quantitatively. By *almost complete* accord is meant one in which all the principal minerals recognized in establishing the norm are actually present in the rock in approximately the same proportions as in the norm, or else standard minerals not calculated in the norm or non-standard minerals are present in such small amounts as not to affect the position of the rock in the system. In these cases of complete or almost complete accord the rock may be said to have a *normative mode.*

A *normative mode* may be defined as one in which the *actual mineral composition* of the rock is so nearly the same as the *standard mineral composition* calculated from the analysis that either may be used to classify the rock correctly.

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[1] *Loc. cit.*

A special and important case of accord between norm and mode is that of the highly feldspathic rocks. It will have been noticed that in the list of standard minerals no reference was made to the plagioclase feldspars intermediate between albite and anorthite (oligoclase, andesine, labradorite, bytownite), nor to the various alkali-feldspars, other than orthoclase and albite, such as microcline and soda-microcline (anorthoclase). This is for the following reasons :

The feldspars present in a rock are seldom of only one kind, several distinct species being present usually, this being true especially of the plagioclases.

The individual plagioclase crystals are frequently zonal, so that an exact determination of the relative amounts is a matter of difficulty if not of impossibility.

When orthoclase, albite and anorthite molecules are present, in rocks of identical chemical composition, the possibilities of combination of these as actual minerals are many. Thus we may have an orthoclase-andesine rock, in which all the albite has crystallized with the anorthite, or an anorthoclase-labradorite rock, where some of the albite has crystallized with the orthoclase.

We therefore classify rocks, as far as the feldspars are concerned, by the calculated molecules of orthoclase, albite and anorthite, irrespective of their actual mineral combinations. The proportions of these will give the *mean composition* of the feldspars. Any of the possible combinations will then be *normative* in the sense above, provided that none or only a negligible amount of the feldspathic molecules crystallize as lenads.

If it should be desired to indicate in the name which combination is actually present, this can be done by the use of the appropriate feldspar name, as described later. Since, however, the albite molecules crystallize with those of anorthite, if these are present in any quantity, it will be necessary to distinguish only the cases in which the albite molecule has crystallized with that of orthoclase, as soda-orthoclase.

2. APPRECIABLE DIFFERENCE BETWEEN THE NORM AND MODE. —Abnormative minerals (whether standard or not) are in such

cases present in quantities which are not negligible, so that the rock cannot be classified directly from the minerals actually present without consideration of the mutual changes involved in the diverse crystallization of the various minerals possible. Such modes may be called *abnormative.*

The abnormative modes may be referred to two kinds, of which the second is by far the most important and common, though the first naturally precedes it in the discussion.

a) The minerals present may be all standard, but differ from those of the norm either in kind or relative proportions, or both. This case is generally due to shifting of the SiO_2 and TiO_2, and may be illustrated by these instances: quartz and leucite crystallize instead of orthoclase, albite instead of nephelite with leucite, as in leucite-basanites and tephrites, quartz with olivine as in quartz-basalts, hypersthene with nephelite, titanite instead of perofskite or ilmenite, the silica in this case coming from normative feldspar molecules. The normative corundum may also form muscovite with molecules of orthoclase and water.

These cases, it will be seen, affect the mineral molecules of oxides capable of combining in more than one proportion with SiO_2, namely K_2O, Na_2O, $(Fe,Mg)O$. All of these modifications are within the range of the standard salic and femic minerals, and if not accompanied by notable amounts of non-standard minerals (as augite or hornblende), may be called respectively *salic*, *femic*, or *salfemic* abnormative modes, according as the abnormative minerals belong to one or the other or both groups.

b) The mode may differ from the norm through the presence of alferric (aluminous ferromagnesian) minerals, augite, hornblende, biotite, garnet, etc.

As is explained in the Part on Calculation, and as is evident on consideration of the subject, the formation of any of these minerals involves changes in some, if not all, of the standard minerals calculated as present in the norm. While minerals of both the standard salic and femic, and non-standard alferric groups are involved, yet it will be sufficient to characterize these modes as *alferric.*

In both the above cases *a* and *b* it is evident that, given the knowledge of the norm and the mutual interrelations between the rock-making minerals which will be explained in the Part on Calculation, it is only necessary to know the amount of abnormative minerals, whether standard or not, to be able to ascertain the changes from the norm which their presence involves. These distinguishing minerals therefore may be called *critical* ones.

The question of how far quantitative distinctions based on the amounts of the critical minerals are to be introduced into the classification is discussed in connection with the nomenclature.

Having thus explained the various relations possible between norm and mode, it will be well to summarize the correspondence observed in fact among the different Classes. It is obvious that no one systematic method of calculation of mineral composition from the chemical can correspond with all the varying possibilities of actual mineral development. The method adopted by us, however, being founded on the most frequently observed mineral relations in igneous rock and on the most generally applicable principles, should yield norms which correspond with the mode in the majority of cases.

This is a point which can only be tested by appeal to the literature of petrography, and comparison of the calculated norms with the modes as furnished by the descriptions. We have, it may be stated here, tested our proposed method in regard to this point very thoroughly upon many hundreds of rock analyses, and especially by means of a collection made by one of us (H. S. W.) of all analyses of igneous rocks which have been published since 1883, amounting to over three thousand.[1]

This comparison shows that the accord between norm and mode is complete or nearly so in the very great majority of rocks of Class I and in the greater portion of those of Class II, these two classes comprising over three-quarters of the known or analyzed igneous rocks of the globe. The accord is also very good in Class V, which includes but few rocks. Classes III and IV show less constant accord, as is to be expected in view of their composition. The results of our proposed method of calculation may therefore be regarded as satisfactory.

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[1] It is hoped that this collection, which will show the norm in every reliable case, will appear shortly after the publication of the present paper, and it will serve as a general illustration of the system. Although not as yet available to others, it has been appealed to as a practical check throughout our discussions, so that the system cannot be regarded as merely academic, but as having been tested at every possible point.

VARIETIES.—It is evident that within the range of possible variations in each of these modes for a given magma unit, there may be mineralogical distinctions among the quite subordinate components, and that it may be desirable to recognize these differences as distinguishing features of rocks. The method of accomplishing this is by considering the several subdivisions upon this basis as *Varieties*, more specifically *Modal Varieties*.

A *Modal Variety* of a petrographical unit of whatever degree, such as Class, Order, Rang, etc., may be defined as a rock having a mode with a slightly different development of the quite subordinate component minerals.

For example, a rock belonging to Class I composed of an extreme amount of feldspar (5th Order) may have 10 per cent. of nephelite actually crystallized, whereas the norm contains no nephelite, the difference having been brought about by the development of a small amount of hypersthene or of hornblende instead of olivine.

The development of a small amount of hornblende, or of biotite, in a rock with a normative mode also constitutes a Modal Variety. The presence of small (not notable) amounts of rare or otherwise noteworthy minerals may also thus be recognized as varieties.

Indeterminable Modes.—Rocks not completely crystallized, containing glass base, and those which for any reason do not permit the determination of all the component minerals, must be classified in the first instance in each case by comparison of the observed minerals with the norm calculated from the chemical analysis of the rock, and subsequently, by analogy with holocrystalline rocks of similar chemical composition whose texture is somewhat like that of the rock in question and whose actual mineral components can all be determined.

Texture.

The terms *structure* and *texture* are commonly used in petrography as synonyms, although efforts have been made to discriminate between them. It seems to us desirable to employ them in different senses, and we propose to limit the use of the term *structure* to those large features of rock bodies which are known as columnar structure, spheroidal parting, platy parting, bedding, brecciation and others. And we use *texture* for the material features of rocks exhibited by the mineral components and by the groundmass of dense or glassy rocks, whether they are viewed megascopically or microscopically. These features are the expression of the mutual relations of the mineral particles or vitreous portions of rocks.

The texture of igneous rocks is one of their most variable characters. It depends in very large degree upon extraneous conditions influencing the consolidation of the magma and in far less degree upon certain relationships between the forms of the rock-making minerals. The factors influencing it are many. Nearly the whole range of textures may be developed in rocks from a single magma consolidating under different conditions. Consequently the use of texture as a primary factor in the classification of igneous rocks can only result in the wide separation of things alike in chemical and mineral characters, which, on the grounds discussed in the preceding pages, are believed to be of greatest systematic importance.

Its use as a prominent factor in classifications has been in most cases coupled with assumptions or assertions known to be by no means strictly in accordance with facts. When such a use of texture is to be made, it is necessary to assume that all rocks possess some one of the few textures at present employed in classification, such as the granular, porphyritic, trachytoid, glassy, etc. This further requires that these textures be so broadly defined that they are robbed of much of their natural descriptive value, or that the definitions be so restricted that they are not appropriate to many of the rocks to be classified.

It has been common to assume a fictitious dependence of texture upon geological occurrence, ignoring other conditions which are plainly of much influence; as, for example, the assumption that granular rocks are plutonic or deep-seated, or, from the converse point of view, that effusive rocks must be partially glassy, or trachytic, or porphyritic.

Less often definitions of texture have involved assumptions of their origin only partially in accord with the facts.

In some cases rocks have been classified on a basis of only part of their texture, as when in certain porphyritic rocks the texture of the groundmass alone has been taken into consideration.

It appear to us that the use of texture in previous petrographic classifications has, on the one hand, weakened the systems by rendering them unnecessarily artificial and illogical, and, on the other hand, has prevented the natural application of certain textural terms. The classificatory rôle assigned to texture in this system is that of a qualifier of any of the various divisions based upon chemical and mineral characters. We present certain general considerations of rock textures which may aid in securing for the various factors which enter into texture a recognition which it seems to us they have not thus far commonly secured. The discussion does not profess to be complete as to all rock textures but simply takes up some of the more prominent textures and discusses their essential properties and relations.

When we consider the texture of igneous rocks we find that it may be separated into three factors, which though not in all cases absolutely distinct from one another are so to a very considerable extent. They are:

I. *Crystallinity.* The degree of crystallization.

II. *Granularity.* The magnitude of the crystals.

III. *Fabric.* The shape and arrangement of the crystalline and non-crystalline parts.

Various textural modifications of igneous rocks may be distinguished from one another, but it is understood that in this respect, as in all others, there are all gradations between different textures. Moreover, all known textures are not developed within every known magma unit, and some textures are specially frequent in rocks of particular compositions.

I. CRYSTALLINITY.— The degree of crystallization attained by an igneous rock is measured by the relative amounts of crystallized and glassy portions. Perfectly glassy rocks are very uncommon, since most obsidians abound in microscopic crystals, while many lavas that are almost completely crystallized contain small amounts of glass. Most rocks are holocrystalline, and all gradations between the extremes exist.

Distinctions that have been based on crystallinity are of two sorts: one an absolute distinction based on the known absence or presence of glass base or matrix, resulting in (*a*) *holocrystalline*, (*b*) *hypocrystalline*, *or partly crystalline*, and (*c*) *holohyaline*, *or completely glassy*, rocks. The other sort of distinctions are less definite, being based on the megascopic appearance of the rock, but they are of great practical value. They are (*a*) *phanerocrystalline*, (*b*) *aphanitic*, and (*c*) *vitreous*.

Phanerocrystalline rocks are generally *holocrystalline*.

Aphanitic rocks are in some instances microscopically *holocrystalline*, in others *hypocrystalline*. Because in some cases it is not possible without microscopical study to determine the presence or absence of glass matrix, it is extremely useful to refer a rock to this textural division. It is discussed again in the next phase of the subject.

Vitreous rocks are *hypohyaline* or *holohyaline*.

II. GRANULARITY is the quality based on the absolute size of the crystals, which, when all igneous rocks are considered, range from microscopic sizes to megascopic ones measured in feet. The quality derived from the relative sizes of the crystals in one rock may be considered as a phase either of granularity or of fabric.

Distinctions based on differences in the absolute size of the grain of rocks have never been sharply defined, because the crystals in an igneous rock are never of uniform size. They vary among themselves considerably in most cases, and it is the average size which is in mind when reference is made to the grain of a rock.

The most important distinction made on this basis is for practical purposes, namely, that between *phanerocrystalline* (phaneric) rocks, whose crystals may be seen by the unaided eye, and *aphanitic* or *cryptocrystalline* rocks, whose crystals are not apparent megascopically. The term *aphanitic* is the better one to use in most cases, because the term cryptocrystalline implies the holocrystalline character of the rock, which may not have been determined. This fact is well expressed by the negative term aphanitic.

Phaneric (phanerocrystalline) rocks are commonly divided into *coarse-grained*, *medium-grained*, and *fine-grained*. But for these terms no limits have been set except those suggested by Zirkel,[1] namely, that the first include all those whose average grain is larger than the size of peas; that the second range from the size of peas to that of millet seeds; and that fine-grain include those of the size of millet seeds and smaller. Translating this into millimeters we would suggest the following scale:

Fine-grained rocks, average grain 1 millimeter or less.

Medium-grained rocks, average grain 1 to 5 millimeters.

Coarse-grained rocks, grain more than 5 millimeters.

Aphanitic rocks have never been systematically divided on a basis of the size of the microscopic crystals, though terms borrowed from the megascopical nomenclature have been adopted to fit the case. These are: *microcrystalline*, which is equivalent to microphanerocrystalline, and applies to textures whose grains can be seen with a microscope; and *microcryptocrystalline*, which includes textures whose grains cannot be seen with a microscope, but which are recognized as present by the exhibition of aggregate polarization between crossed nicols.

In place of distinctions corresponding to coarse, medium, and fine-grain, which are useful when megascopically applied, it is possible to describe the average measured diameter of microscopic crystals. But there appears to be no demand for systematic subdivisions based on the magnitude of these minute textures.

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[1] *Lehrbuch der Petrographie*, Vol. I, p. 456, 1893.

Textural distinctions based on the relative sizes of the crystals in one rock recognize (1) *evenly granular* or *non-porphyritic* rocks, and (2) *porphyritic* rocks. These distinctions cannot be sharply drawn, because, as already said, it almost never happens that all crystals in a rock are the same size. Moreover, there is a great variety of ways in which differences of size in crystals may exhibit themselves.

The difference of size which constitutes *porphyritic* texture may be defined as that in which the size of some crystals is so much larger than that of a sufficient number to form a matrix for the first, that the larger ones appear notably distinct from the matrix or groundmass. There are *porphyritic* rocks with phaneric (phanerocrystalline), aphanitic, or glassy, groundmasses, the phenocrysts being megascopically notable. And there are microporphyritic aphanitic or glassy rocks, in which the phenocrysts are not megascopically notable, although they may be visible.

Granular and porphyritic textures may also be considered as modifications of the fabric.

III. FABRIC.—The *arrangement of the crystalline* and *non-crystalline* parts of a rock, or its *fabric*, as we propose to call it, is dependent on (1) the shapes of the crystals, and (2) their positions with respect to one another and to the glass base when present.

When considered with reference to all the minerals in the rock the fabric of most rocks is so complex that no simple expression is applicable to it, and nearly all the formal relations which it is customary to distinguish as different rock textures frequently exist in one rock. However, it usually happens that certain features dominate in each case while others may be quite insignificant though present. Hence we may again disregard those which do not occur to a notable extent and use those which predominate as the means of discrimination, that is, as a basis for textural subdivision.

1. As to the shape of the constituent crystals, there are two distinctions of a general nature:

(*a*) *Automorphic*[1] (idiomorphic) forms, in which the crystal form has been developed more or less perfectly.

(*b*) *Xenomorphic*[1] (allotriomorphic) forms, in which the proper crystal form has not been developed owing to interference from outside influences.

These latter forms are of two kinds: one caused by the interference of adjacent crystals, the commonly recognized case in holocrystalline rocks; the other is caused by outward forces acting in the liquid from which crystallization has taken place, which produce irregularly shaped crystals peculiar to microscopic growths in the more siliceous glasses, but not confined to them.

Other distinctions of shape depend on the particular forms of the crystals, whether equidimensional, tabular, prismatic, or otherwise.

2. The arrangements or positions of crystals with respect to one another may be grouped under several heads:

A. *Juxtaposition.*—In this case, although subordinate minerals may be enclosed in the preponderant ones, the preponderant minerals are adjacent to one another, and the following divisions based on the shape of the crystals are recognized:

Granular, in which adjacent crystals have nearly the same size, so that the rock appears to be made up of more or less uniform grains. According to the form of the individual crystals the rock is said to be:

a) *Xenomorphic granular*, in which the crystals are xenomorphic and equidimensional. This is commonly called "granitic" fabric.

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[1] We adopt the use of *automorphic* and *xenomorphic* instead of *idiomorphic* and *allotriomorphic*, as they have undoubted priority, Rohrbach having used the former in 1886 (*T. M. P. M.*, Vol. VII, p. 88), while Rosenbusch introduced the latter terms in 1887. Rohrbach's terms have the further advantage of being shorter.

b) *Hypautomorphic granular*, in which some of the crystals, or parts of some crystals, are automorphic, while others are xenomorphic.

c) *Panautomorphic granular*, in which all the crystals possess their proper forms more or less perfectly. Of course absolute automorphism cannot exist in a compact, continuous rock. The precise character of this fabric depends on the kinds of minerals present and on their particular habit. It is, therefore, different in rocks of different compositions so far as observed.

Tabular or prismatic fabric.—There is further modification of it in case the shapes of some of the minerals are *tabular* or *prismatic*. In such cases there may be distinctions according as there is: no definite arrangement of plates or prisms, which stand in all positions; or a regular arrangement in more or less parallel directions (*fluidal* or *parallel fabric*), or in more or less radiatng directions (*radiate fabric*).

B. *Interposition* (inclusion).—The arrangements of crystals referred mainly to inclusion of one by another are of two principal kinds:

a) *Graphic fabric.*— One in which two minerals mutually inclose one another, by interpenetration. This is shown by the parallel orientation of several parts of each mineral. The familiar example is the *graphic* intergrowth of quartz and feldspar.

b) *Poikilitic fabric.*—The second kind of interposition fabric is that in which one mineral acts as a matrix for one or more kinds of other minerals which do not possess parallel orientation. This is exhibited by various rocks, in some of which hornblende crystals form the matrix, in others orthoclase, in others quartz.

Ophitic fabric is a special case of poikilitic, in which plagioclases are inclosed in augite crystals, the feldspars being relatively large when compared with the areas of augite.

C. *Porphyritic fabric* is one characterized by the presence of crystals surrounded by a matrix noticeably distinct from them. These crystals are known as *phenocrysts*. The matrix or groundmass may be crystalline or glassy. The phenocrysts are megascopic in some cases, and microscopic in others. When they are microscopic in a glassy matrix the fabric is called *microlitic glassy.*

D. *Orbicular fabrics.*—There are complex fabrics so frequent and so characteristic that they have formed bases for textural divisions. They are:

a) *Spherulitic*, allied to the microlitic fabric in some cases in that it can be traced to special forms of microscopic crystallization, consisting of radiating prisms. It is further allied to porphyritic fabric, in that it may be developed locally in the magma and produce scattered spherulites of notable size, and having the appearance of phenocrysts.

b) *Spheroidal*, closely like spherulitic in some cases, where there is crude radial arrangement of crystals, but quite different from it in others in which there are concentric granular shells. A somewhat diverse form of aggregate crystallization occasionally developed in phaneric rocks.

HETEROGENEOUS TEXTURES produced by more or less heterogeneity in the magma are distinguished by marked variability of (*a*) fabric, or (*b*) composition.

a) *Eutaxitic texture.*—Variability of fabric is exhibited by some banded or streaked lavas (rhyolites) in which alternate layers of rock exhibit different degrees of crystallinity or different arrangements of crystals. Variability of texture on a large scale is often exhibited by phaneric rocks of similar composition (granitic pegmatites).

b) Variability of composition may not strictly belong to the discussion of the texture of rock, but the two are intimately blended, and the treatment of the matter in this place may be justified. It results in *banded textures*, approaching gneissic, and is exhibited in certain gabbros; also in irregularly streaked textures, known in German as *Schlieren*, which may be called *schlieric textures.*

In classifying rocks on a basis of textural differences we have considered the fabric, or the shape and arrangement of the crystals, as more fundamental than the crystallinity or granularity, for the reason that it is more clearly a function of the composition of the magma, since it depends upon the shapes of the crystals which are often characteristic of particular minerals which preponderate in rocks of certain compositions.

On the other hand it is possible for any magma to attain any degree of crystallinity, although all degrees, from glassy to holocrystalline, are not known for all kinds of magmas. In the same way any magma may develop any grade of granularity, although some grades are oftener observed in certain kinds of magmas than in others.

The method of recognizing these differences of texture and of introducing them into the classification is referred to the nomenclature, where it will be fully stated.

PART II. NOMENCLATURE.

Having outlined the system of classification proposed by us, it is necessary to present and discuss the nomenclature which we have constructed for its expression and use.

As already pointed out, the present system of nomenclature is most unsatisfactory, for the reasons that it furnishes no distinctions between names of different values (one termination alone being regularly used), nor indication of the relations of any of the groups.

Furthermore, since the system of classification here proposed is based on relations and principles quite distinct from those in present use, the old names cannot be employed for the new divisions. This is obvious for the reason that the new divisions do not cover the same concepts or characters as the old ones, and because the use of an old name with a new meaning is to be shunned as leading to grave misunderstanding and confusion.

Rock names, like those of any other system of nomenclature, are, or should be, composed of two parts, with distinct functions, viz., the *body* or *root*, and the *termination*. The former expresses either directly, or by implication or connotation, the character of the object or group of objects to which it is applied, and the latter indicates the place of the object or group in the co-ordinated system, from the broadest to the smallest division. Each separate division, from the largest to the smallest, should have a distinctive appellation, precluding confusion with others, and indicating at once its relative place in this system and its character. The names should be mnemonic, if possible, expressing the idea to be conveyed, short, euphonious, and not liable to be mistaken for one another.

In accordance with the principles just stated, we have constructed names for the various magmatic divisions which have been explained in the preceding pages on classification. In addition to these it will be necessary to employ qualificatory terms to express the variable characters of mineral composition and texture, which, with the appropriate magmatic name, will apply to the rocks themselves. The nomenclature, then, will be to a certain extent polynomial. These qualifiers may be applied at any point in the system.

MAGMATIC NAMES.

TERMINATION.—It is possible to indicate the place of any given rock name in a system by employing only one termination and by varying the root of the word, which then alone indicates at the same time both the character of the group and its relative position in the system. Thus, with the single termination *-ite* the family name, foyaite, expresses the concept of rocks formed essentially of alkali-feldspar and nephelite, while smaller divisions of this are indicated by such names as laurdalite, litchfieldite and lujavrite.

But this method is very unsatisfactory and primitive, in that it does not avail itself of the very powerful aid afforded by such possible terminations as would in themselves give considerable knowledge of the group named. Furthermore, while feasible with a small number of names, such a method involves a great tax on the memory, especially with the rapid growth of our knowledge of rocks and of new rock types, and the necessity for new names.

These serious objections to the use of but one termination have so far been scarcely recognized, and this great defect in present nomenclature is one cause of much of the prevalent outcry against the multiplication of rock names.

To indicate the relative place of the various divisions in the system, from Class to Subgrad, we have adopted a set of terminations which are to be used invariably with their respective divisions. We have endeavored to select those which are at the same time: mnemonic in suggesting the relative positions of the divisions ; euphonious ; not in previous use to any great extent ; and as far as possible adapted to use in all European languages. The termination -ite is rejected because it is already in use, not only in petrography but in mineralogy, to which latter science, as having a prior claim, we suggest that it be restricted. The terminations proposed are as follows :

Class,	-ane.	Subclass.	-one.
Order,	-are.	Suborder,	-ore.
Rang,	-ase.	Subrang,	-ose.
Grad,	-ate.	Subgrad,	-ote.

These terminations were selected after trial of many that were suggested. The distinctive consonants, *n*, *r*, *s*, *t*, are in their alphabetical order, suggesting the sequence of the taxonomic divisions to which they refer. The vowels, *a* and *o*, were considered best to indicate the distinctions between each principal division and its subdivisions. And the final *e* is added in English to lengthen the sound of these vowels, but it may be omitted when the words are used in other languages.

The name of a magma belonging to a *Section* of any given division will receive the termination of that particular division preceded by the letter *i*, since it occupies the same relative position in the scheme as the division in question, although of somewhat different taxonomic character.

Root.—In choosing the root of the name two methods are available. This part may be a syllable or syllables derived from local or personal names or chosen arbitrarily, giving only by connotation an idea of the character of the group named; or it may be composed of syllables which will of themselves, by proper selection on mnemonic grounds, give an idea of th character.

The latter method would seem at first sight to be the better, since it apparently involves less tax on the memory. We have, however, made many attempts at the construction of such name roots, giving them practical trials at all points of the scheme, but have been forced to reject this method for all divisions except that of Class, for the following reasons:

1. The names are apt to be excessively long and cumbrous, especially in the smaller divisions.

2. While the distinctions can be readily seen on paper, yet close attention must be paid to each syllable and even to each letter, and in spoken language the names are so similar as to be confused with each other.

3. As a consequence, the mnemonic quality, which is the great theoretical advantage of this method, is very seriously diminished, especially in the smaller divisions.

4. The adoption of this method involves a fixation or lack of elasticity in the nomenclature, which would be fatal to it, if the need arose for any change either in the method of arriving at the divisions or in their number, since this would involve a corresponding change in the nomenclature.

We have, therefore, except for Classes and Subclasses, adopted roots derived from names of localities, taking advantage of the fact that there are at present many of these in present petrographical nomenclature with connoted magmatic ideas which are readily adaptable to our purpose. Thus with the root *nordmark* is connoted the idea of an alkali-feldspathic rock, with *miask* that of a rock composed essentially of alkali-feldspar and nephelite. These are, it is true, not the only connotations of these names, since in both of them are also implied ideas of texture.

In the names suggested subsequently we have endeavored to adhere to the following principles in the selection of roots.

a) They should be adjusted to the relative position of the divisions to which they are applied. That is, the roots of names which are at present in use for large rock groups, or which were proposed by the author for such groups, are used for the larger divisions, such as Rangs, while those which have at present, or were originally given, narrower or more specific character or application, are used for the smaller divisions, Subrangs, Grads, and Subgrads.

Inasmuch as few if any of the rock names at present in use, even the broadest, cover the wide mineralogical concepts involved in our proposed Orders, and as it will also be well to make the names of these broad groups quite distinctive, we have adopted as the source of the roots for Orders the names of countries. We have endeavored to select in each case the name of a country where the respective Order is found in especial abundance or is most typically represented, or which is historically connected with the Order. This is, of course, not possible in every case, as some of the most abundant Orders are represented in several countries. In such cases we have endeavored to apportion the ordinal roots equitably among the petrographically prominent nations.

b) The selection should be based on rocks of which good analyses exist. This is obviously just, since a poor analysis is of little use, and is often of positive harm, to the science and to any system of classification, and furthermore it will frequently happen that a name based on such will prove eventually to have been misapplied.

c) A locality root already in use should be employed if possible.

d) As far as is consistent with the preceding principles, the laws of priority will hold good, as usually recognized and as formulated in Dana's *System of Mineralogy*.

e) In selecting a new root from several possible localities, the one should be chosen which is best known, has been best described, or which furnishes the most typical material.

f) The roots should be short, if possible not more than two syllables, and euphonious.

g) The name of a locality where the mode is normative is to be employed if possible.

h) As far as possible localities whose rocks occur near the classificatory borders of a given group are to be avoided.

Intermediate magmatic names.—A rock, whose composition is such that its magma occurs so near the border line of any division of the system as to be considered a transition magma, receives a compound magma name, made by uniting the names of the two divisions concerned, and connecting them with a hyphen. The name of the division in which the rock occurs is to be preceded by that of the neighboring division.

NAMES.—As the Classes are few in number the strictly mnemonic method of root-formation is applicable to them, and we have accordingly named them on the basis of the relative amounts of the standard salic and femic minerals present, these being indicated by the syllables *sal* and *fem*, as already explained. The relative amounts are shown by the prefixes *per-* and *do-*, which stand respectively for *extremely abundant* and *dominant.* The names for the five classes are as follows :

1. Persalane: Extremely salic—$\frac{\text{Sal}}{\text{Fem}} > \frac{7}{1}$.
2. Dosalane: Dominantly salic—$\frac{\text{Sal}}{\text{Fem}} < \frac{7}{1} > \frac{5}{3}$.
3. Salfemane: Equally salic and femic—$\frac{\text{Sal}}{\text{Fem}} < \frac{5}{3} > \frac{3}{5}$.
4. Dofemane: Dominantly femic—$\frac{\text{Sal}}{\text{Fem}} < \frac{3}{5} > \frac{1}{7}$.
5. Perfemane: Extremely femic—$\frac{\text{Sal}}{\text{Fem}} < \frac{1}{7}$.

For other magma units names derived from geographical localities have been used, as already explained. Those suggested by us apply to the more important divisions of the system, and to those based on the best established data, derived from the collection of several thousand analyses already referred to, and from older analyses where available. There are numerous divisions for which we have not sufficient data to warrant our suggesting names at this time. Owing to the large number of names selected, they are presented in tabulated form, in such manner that they can be understood without difficulty.

A list of all new words proposed by us, with their definitions, will be found in a Glossary which will appear with a reprint of this essay, to be published in book form by the University of Chicago Press. The Glossary and the Tables to aid the calculation of norms are too voluminous to be printed in this JOURNAL.

ROCK NAMES.

As just explained, the names to be applied to the systematic divisions, or magma units, are formed from names of geographical localities modified by a series of terminations, and designate rocks so far as their chemical composition and standard mineral composition are concerned, but do not indicate their actual mineral composition or their texture. The methods of expressing these latter characters in the systematic nomenclature remain to be stated. As already said, each is treated independently of the other. We take up first the expression of the actual mineral composition.

ACTUAL MINERAL COMPOSITION.—A nomenclature that will express the mode of a rock must indicate the kinds of minerals present and their quantity. The question then arises: How far is it necessary to modify, or qualify, the magmatic names in order to accomplish this, and further: What exactness is desirable in expressing the quantity of the actual minerals present?

When the name of the magma unit to which a rock belongs is given, there is implied in it the standard mineral composition, or *norm*, and in order to describe the actual mineral composition, or *mode*, of the rock it is only necessary to state the extent to which this differs from the norm.

And since quantitative distinctions within a petrographical unit of the smallest magmatic division established by this system would further subdivide these units, it does not appear desirable in the present state of petrographical science to carry such subdivision to any considerable extent, however desirable it may become in the future.

If the mode be *normative*, that is, if there be complete or almost complete accord between the standard mineral composi-

CLASS I, PERSALANE, $\frac{SAL}{FEM} > \frac{7}{1}$. SUBCLASS I, PERS

ORDER	1, $\frac{Q}{F} > \frac{7}{1}$ VICTORARE.	2, $\frac{Q}{F} < \frac{7}{1} > \frac{5}{3}$ *BELGARE.*	3, $\frac{Q}{F} < \frac{5}{3} > \frac{3}{5}$ COLUMBARE.	4, $\frac{Q}{F} < \frac{3}{5}$ BRITANN
RANG 1, PERALKALIC, $\frac{K_2O+Na_2O}{CaO} > \frac{7}{1}$		1. *Dargase*	1. *Alaskase*	1. *Liparas*
Subrang 1, Perpotassic, $\frac{K_2O}{Na_2O} > \frac{7}{1}$			1. x	1. Lebach
Subrang 2, Dopotassic, $\frac{K_2O}{Na_2O} < \frac{7}{1} > \frac{5}{3}$			2. Magdeburgose	2. Omeose
Subrang 3, Sodipotassic, $\frac{K_2O}{Na_2O} < \frac{5}{3} > \frac{3}{5}$			3. Alaskose	3. Liparo
Subrang 4, Dosodic, $\frac{K_2O}{Na_3O} < \frac{3}{5} > \frac{1}{7}$			4. x	4. Kalleru
Subrang 5, Persodic, $\frac{K_2O}{Na_2O} < \frac{1}{7}$			5. Westphalose	5. Noyan
RANG 2, DOMALKALIC, $\frac{K_2O+Na_2O}{CaO} < \frac{7}{1} > \frac{5}{3}$		2. x	2. *Alsbachase*	2. *Toscan*
Subrang 1, Perpotassic, $\frac{K_2O}{Na_2O} > \frac{7}{1}$		1. x	1.	1.
Subrang 2, Dopotassic, $\frac{K_2O}{Na_2O} < \frac{7}{1} > \frac{5}{3}$			2. Mihalose	2. Dellen
Subrang 3, Sodipotassic, $\frac{K_2O}{Na_2O} < \frac{5}{3} > \frac{3}{5}$		2. x	3. Tehamose	3. Toscan
Subrang 4, Dosodic, $\frac{K_2O}{Na_2O} < \frac{3}{5} > \frac{1}{7}$		3. x	4. Alsbachose	4. Lassen
Subrang 5, Persodic, $\frac{K_2O}{Na_2O} < \frac{1}{7}$			5. Yukonose	5. Maripo
RANG 3, ALKALICALCIC, $\frac{K_2O+Na_2O}{CaO} < \frac{5}{3} > \frac{3}{5}$		3. x	3. *Riesenase*	3. *Colorad*
Subrang 1, Perpotassic, $\frac{K_2O}{Na_2O} > \frac{7}{1}$		1	1.	1.
Subrang 2, Dopotassic, $\frac{K_2O}{Na_2O} < \frac{7}{1} > \frac{5}{3}$			2. x	2. x
Subrang 3, Sodipotassic, $\frac{K_2O}{Na_2O} < \frac{5}{3} > \frac{3}{5}$		2. x	3. Riesenose	3. Amiat
Subrang 4, Dosodic, $\frac{K_2O}{Na_2O} < \frac{3}{5} > \frac{1}{7}$		3. x	4. x	4. Yellow
Subrang 5, Persodic, $\frac{K_2O}{Na_2O} < \frac{1}{7}$			5. Vulcanose	5. Amad
RANG 4, DOCALCIC, $\frac{K_2O+Na_2O}{CaO} < \frac{3}{5} > \frac{1}{7}$			4. x	4. x
Subrang 1, Prepotassic, $\frac{K_2O}{Na_2O} > \frac{5}{3}$			1. x	1.
Subrang 2, Sodipotassic, $\frac{K_2O}{Na_2O} < \frac{5}{3} > \frac{3}{5}$			2. x	2.
Subrang 3, Presodic, $\frac{K_2O}{Na_2O} < \frac{3}{5}$			3.	3. x
RANG 5, PERCALCIC, $\frac{K_2O+Na_2O}{CaO} < \frac{1}{7}$				

NOTE.— X indicates that analyses are known which belong to this division, but that no name is suggested by us.

$\frac{AL}{EM} > \frac{7}{1}$. SUBCLASS I, PERSALONE, $\frac{QFL}{CZ} > \frac{7}{1}$.

$<\frac{7}{1}>\frac{5}{3}$ *GARE.*	3. $\frac{Q}{F}<\frac{5}{3}>\frac{3}{5}$ COLUMBARE.	4, $\frac{Q}{F}<\frac{3}{5}>\frac{1}{7}$ BRITANNARE.	5. $\frac{Q.\ L}{F}<\frac{1}{7}$ CANADARE.	6, $\frac{L}{F}<\frac{3}{5}>\frac{1}{7}$ RUSSARE.	7, $\frac{L}{F}<\frac{5}{3}>\frac{3}{5}$ TASMANARE.	8, $\frac{L}{F}<\frac{7}{1}>\frac{5}{3}$ ONTARARE.	9, $\frac{L}{F}>\frac{7}{1}$ x
rgase	1. *Alaskase*	1. *Liparase*	1. *Nordmarkase*	1. *Miaskase*	1. *Laugenase*	1.............	1..........
....	1. x	1. Lebachose	1.............	1.............	1.............	....	....
....	2. Magdeburgose	2. Omeose	2.............	2.............	2.............	....	....
....	3. Alaskose	3. Liparose	3. Phlegrose	3. Beemerose	3. x	....	....
....	4. x	4. Kallerudose	4. Nordmarkose	4. Miaskose	4. Laugenose	....	....
....	5. Westphalose	5. Noyangose	5. Tuolumnose	5. Mariupolose	5.............	....	....
x	2. *Alsbachase*	2. *Toscanase*	2. *Pulaskase*	2. *Viezzenase*	....	....	....
x	1.............	1.............	1.............	1.............	....	....	....
	2. Mihalose	2. Dellenose	2. Vulsinose	2.............	....	....	....
x	3. Tehamose	3. Toscanose	3. Pulaskose	3. x	....	....	....
x	4. Alsbachose	4. Lassenose	4. Laurvikose	4. Viezzenose	....	....	....
	5. Yukonose	5. Mariposose	5. x	5.............	....	....	....
x	3. *Riesenase*	3. *Coloradase*	3. x	3.............	....	....	....
....	1.............	1.............	1.............	....	....	....	....
	2. x	2. x	2. x	....	....	....	....
x	3. Riesenose	3. Amiatose	3. x	....	....	....	....
x	4. x	4. Yellowstonose	4. x	....	....	....	....
	5. Vulcanose	5. Amadorose	5. x	....	....	....	....
....	4. x	4. x	4. *Labradorase*	4. x	....	....	....
....	1. x	1.............	1.............	1.............	....	....	....
....	2. x	2.............	2.............	2.............	....	....	....
....	3.............	3. x	3. Labradorose	3. x	....	....	....
....	....	....	5. *Canadase*	....	....	....	....

by us.

CLASS II, DOSALANE, $\frac{SAL}{FEM} < \frac{7}{1} > \frac{5}{3}$. SUBCLASS I

ORDER	1, $\frac{Q}{F} > \frac{7}{1}$	2, $\frac{Q}{F} < \frac{7}{1} > \frac{5}{3}$	3, $\frac{Q}{F} < \frac{5}{3} > \frac{3}{5}$ HISPANARE.	4, $\frac{Q}{F} < \frac{3}{5}$ AUSTRA
RANG 1, PERALKALIC, $\frac{K_2O+Na_2O}{CaO} < \frac{7}{1}$			1. *Varingase*	1. *Pantell*
Subrang 1, Perpotassic, $\frac{K_2O}{Na_2O} > \frac{7}{1}$			1	1
Subrang 2, Dopotassic, $\frac{K_2O}{Na_2O} < \frac{7}{1} > \frac{5}{3}$			2	2
Subrang 3, Sodipotassic, $\frac{K_2O}{Na_2O} < \frac{5}{3} > \frac{3}{5}$			3. Varingose	3. Grorud
Subrang 4, Dosodic, $\frac{K_2O}{Na_2O} < \frac{3}{5} > \frac{1}{7}$			4. x	4. Pantell
Subrang 5, Persodic, $\frac{K_2O}{Na_2O} < \frac{1}{7}$			5	5
RANG 2, DOMALKALIC, $\frac{K_2O+Na_2O}{CaO} < \frac{7}{1} > \frac{5}{3}$			2. x	2. *Dacase*
Subrang 1, Perpotassic, $\frac{K_2O}{Na_2O} > \frac{7}{1}$			1	1
Subrang 2, Dopotassic, $\frac{K_2O}{Na_2O} < \frac{7}{1} > \frac{5}{3}$			2. x	2
Subrang 3, Sodipotassic, $\frac{K_2O}{Na_2O} < \frac{5}{3} > \frac{3}{5}$			3. x	3. Adame
Subrang 4, Dosodic, $\frac{K_2O}{Na_2O} < \frac{3}{5} > \frac{1}{7}$			4	4. Dacose
Subrang 5, Persodic, $\frac{K_2O}{Na_2O} < \frac{1}{7}$			5	5
RANG 3, ALKALICALCIC, $\frac{K_2O+Na_2O}{CaO} < \frac{5}{3} > \frac{3}{5}$			3. *Almerase*	3. *Tonal*
Subrang 1, Perpotassic, $\frac{K_2O}{Na_2O} > \frac{7}{1}$			1	1
Subrang 2, Dopotassic, $\frac{K_2O}{Na_2O} < \frac{7}{1} > \frac{5}{3}$			2	2. x
Subrang 3, Sodipotassic, $\frac{K_2O}{Na_2O} < \frac{5}{3} > \frac{3}{5}$			3. Almerose	3. Harzo
Subrang 4, Dosodic, $\frac{K_2O}{Na_2O} < \frac{3}{5} > \frac{1}{7}$			4. Sitkose	4. Tonal
Subrang 5, Persodic, $\frac{K_2O}{Na_2O} < \frac{1}{7}$			5	5. Placer
RANG 4, DOCALCIC, $\frac{K_2O+Na_2O}{CaO} < \frac{3}{5} > \frac{1}{7}$			4. x	4. *Banda*
Subrang 1, Prepotassic, $\frac{K_2O}{Na_2O} > \frac{5}{3}$			1. x	1. Sagam
Subrang 2, Sodipotassic, $\frac{K_2O}{Na_2O} < \frac{5}{3} > \frac{3}{5}$			2	2. x
Subrang 3, Presodic, $\frac{K_2O}{Na_2O} < \frac{3}{5}$			3. x	3. Bando
RANG 5, PERCALCIC, $\frac{K_2O+Na_2O}{CaO} < \frac{1}{7}$			5. *Gordonase*	

NOTE.— X indicates that analyses are known which belong to this division, but that no name is suggested by us.

, $\frac{SAL}{FEM}<\frac{7}{1}>\frac{5}{3}$. SUBCLASS I, DOSALONE, $\frac{QFL}{CZ}>\frac{7}{1}$.

$<\frac{7}{1}>\frac{5}{3}$	3, $\frac{Q}{F}<\frac{5}{3}>\frac{3}{5}$ HISPANARE.	4, $\frac{Q}{F}<\frac{3}{5}>\frac{1}{7}$ AUSTRARE.	5, $\frac{Q, L}{F}<\frac{7}{1}$ GERMANARE.	6, $\frac{L}{F}<\frac{3}{5}>\frac{1}{7}$ NORGARE.	7, $\frac{L}{F}<\frac{3}{5}>\frac{5}{3}$ ITALARE.	8, $\frac{L}{F}<\frac{7}{1}>\frac{5}{3}$ CAMPANARE.	9, $\frac{L}{F}>\frac{7}{1}$ LAPPARE.
....	1. *Varingase*	1. *Pantellerase*	1. *Umptekase*	1. *Laurdalase*	1. *Lujavrase*	1. x	1. *Urtase*
....	1..............	1............	1............	1............	1............	1......	1 ....
....	2..............	2............	2Highwoodose.	2. Fergusose	2............	2...........	2 ....
....	3. Varingose	3. Grorudose	3. Ilmenose	3. Judithose	3. Janeirose	3. x	3. Arkansose
....	4. x	4. Pantellerose	4. Umptekose	4. Laurdalose	4. Lujavrose	4...........	4. x
....	5..............	5............	5............	5............	5............	5. x	5. Urtose
....	2. x	2. *Dacase*	2. *Monzonase*	2. *Essexase*	2. *Vulturase*	2. *Vesuvase*	....
....	1..............	1............	1............	1............	1............	1...........	....
....	2. x	2............	2. Ciminose	2. x	2. x	2. Vesuvose	....
....	3. x	3. Adamellose	3. Monzonose	3. Borolanose	3. x	3...........	....
....	4..............	4. Dacose	4. Akerose	4. Essexose	4. Vulturose	4. x	....
....	5..............	5............	5. x	5............	5............	5...........	....
....	3. *Almerase*	3. *Tonalase*	3. *Andase*	3. *Salemase*	3. x	....	....
....	1..............	1............	1............	1. x	1............	....	....
....	2..............	2. x	2. x	2. x	2............	....	....
....	3. Almerose	3. Harzose	3. Shoshonose	3. x	3. x	....	....
....	4. Sitkose	4. Tonalose	4. Andose	4. Salemose	4. x	....	....
....	5..............	5. Placerose	5. Beerbachose	5. x	5............	....	....
....	4. x	4. *Bandase*	4. *Hessase*	4. x	....	....	....
....	1. x	1. Sagamose	1............	1............	....	....	....
....	2..............	2. x	2. x	2............	....	....	....
....	3. x	3. Bandose	3. Hessose	3. x	....	....	....
....	5. *Gordonase*	....	5. *Corsase*	....	....	....	....

by us.

CLASS III, SALFEMANE, $\frac{SAL}{FEM} < \frac{5}{3} > \frac{3}{5}$. SUBCLASS I

ORDER	1, $\frac{Q}{F} > \frac{7}{1}$	2, $\frac{Q}{F} < \frac{7}{1} > \frac{5}{3}$	3, $\frac{Q}{F} < \frac{5}{3} > \frac{3}{5}$ ATLANTARE.	4, $\frac{Q}{F} < \frac{3}{5} >$ VAALAR
RANG 1, PERALKALIC, $\frac{K_2O+Na_2O}{CaO} > \frac{7}{1}$			1. *Rockallase*	1
Subrang 1, Perpotassic, $\frac{K_2O}{Na_2O} > \frac{7}{1}$			1	
Subrang 2, Dopotassic, $\frac{K_2O}{Na_2O} < \frac{7}{1} > \frac{5}{3}$			2	
Subrang 3, Sodipotassic, $\frac{K_2O}{Na_2O} < \frac{5}{3} > \frac{3}{5}$			3. x	
Subrang 4, Dosodic, $\frac{K_2O}{Na_2O} < \frac{3}{5} > \frac{1}{7}$			4	
Subrang 5, Persodic, $\frac{K_2O}{Na_2O} < \frac{1}{7}$			5. Rockallose	
RANG 2, DOMALKALIC, $\frac{K_2O+Na_2O}{CaO} < \frac{7}{1} > \frac{5}{3}$				2
Subrang 1, Perpotassic, $\frac{K_2O}{Na_2O} < \frac{7}{1}$				
Subrang 2, Dopotassic, $\frac{K_2O}{Na_2O} < \frac{7}{1} > \frac{5}{3}$				
Subrang 3, Sodipotassic, $\frac{K_2O}{Na_2O} < \frac{5}{3} > \frac{3}{5}$				
Subrang 4, Dosodic, $\frac{K_2O}{Na_2O} < \frac{3}{5} > \frac{1}{7}$				
Subrang 5, Persodic, $\frac{K_2O}{Na_2O} < \frac{1}{7}$				
RANG 3, ALKALICALCIC, $\frac{K_2O+Na_2O}{CaO} < \frac{5}{3} > \frac{3}{5}$				3. *Vaalase*
Subrang 1, Perpotassic, $\frac{K_2O}{Na_2O} > \frac{7}{1}$				1
Subrang 2, Dopotassic, $\frac{K_2O}{Na_2O} < \frac{7}{1} > \frac{5}{3}$				2
Subrang 3, Sodipotassic, $\frac{K_2O}{Na_2O} < \frac{5}{3} > \frac{3}{5}$				3
Subrang 4, Dosodic, $\frac{K_2O}{Na_2O} < \frac{3}{5} > \frac{1}{7}$				4. Vaalose
Subrang 5, Persodic, $\frac{K_2O}{Na_2O} < \frac{1}{7}$				5
RANG 4, DOCALCIC, $\frac{K_2O+Na_2O}{CaO} < \frac{3}{5} > \frac{1}{7}$				4. x
Subrang 1, Prepotassic, $\frac{K_2O}{Na_2O} > \frac{5}{3}$				1
Subrang 2, Sodipotassic, $\frac{K_2O}{Na_2O} < \frac{5}{3} > \frac{3}{5}$				2
Subrang 3, Presodic, $\frac{K_2O}{Na_2O} < \frac{3}{5}$				3. x
RANG 5, PERCALCIC, $\frac{K_2O+Na_2O}{CaO} < \frac{1}{7}$				

NOTE.—X indicates that analyses are known which belong to this division, but that no name is suggested by us.

, $\frac{SAL}{FEM}<\frac{5}{3}>\frac{3}{5}$. SUBCLASS I, SALFEMONE, $\frac{QFL}{CZ}>\frac{7}{1}$.

$<\frac{7}{1}>\frac{5}{3}$	3, $\frac{Q}{F}<\frac{5}{3}>\frac{3}{5}$ ATLANTARE.	4, $\frac{Q}{F}<\frac{3}{5}>\frac{1}{7}$ VAALARE.	5, $\frac{Q, L}{F}<\frac{1}{7}$ GALLARE.	6, $\frac{L}{F}<\frac{3}{5}>\frac{1}{7}$ PORTUGARE.	7, $\frac{L}{F}<\frac{5}{3}>\frac{3}{5}$ KAMERUNARE.	8, $\frac{L}{F}<\frac{7}{1}>\frac{5}{3}$ BOHEMARE.	9, $\frac{L}{F}>\frac{7}{1}$ FINNARE.
....	1. *Rockallase*	1............	1. *Orendase*	1. *Wyomingase*	1. *Malignase*	1. *Chotase*	1. *Ijolase*
....	1............	....	1. Orendose	1. Wyomingose	1............	1............	1............
....	2............	....	2............	2............	2............	2. Chotose	2. Madupose
....	3. x	....	3............	3. x	3............	3............	3............
....	4............	....	4............	4. x	4. Malignose	4............	4. Iiwarose
....	5. Rockallose	....	5............	5............	5............	5............	5. Ijolose
....	....	2............	2. *Kilauase*	2. *Monchiquase*	2. *Kamerunase*	2. *Albanase*	....
....	....	....	1............	1............	1............	1............	....
....	....	....	2. Prowersose	2............	2............	2. Albanose	....
....	....	....	3. Lamarose	3. Shonkinose	3. x	3. x	....
....	....	....	4. Kilauose	4. Monchiquose	4. Kamerunose	4. Covose	....
....	....	....	5. x	5............	5. x	5. x	....
....	....	3. *Vaalase*	3. *Camptonase*	3. *Limburgase*	3. *Etindase*	....	....
....	....	1............	1............	1............	1............	....	....
....	....	2............	2. Absarokose	2............	2. x	....	....
....	....	3............	3. Kentallenose	3. Ourose	3............	....	....
....	....	4. Vaalose	4. Camptonose	4. Limburgose	4. Etindose	....	....
....	....	5............	5. Ornose	5. x	5. x	....	....
....	....	4. x	4. *Auvergnase*	4. x	4. x	....	....
....	....	1............	1............	1............	1............	....	....
....	....	2............	2. x	2. x	2. x	....	....
....	....	3. x	3. Auvergnose	3. x	3............	....	....
....	....	....	5. *Kedabekase*	....	....	....	....

by us.

	ORDER 1, $\frac{P, O}{M} > \frac{7}{1}$, HUNGARARE.			
SECTION ...	1, $\frac{P}{O} > \frac{7}{1}$ Minnesotiare.	2, $\frac{P}{O} < \frac{7}{1} > \frac{5}{3}$ x	3, $\frac{P}{O} < \frac{5}{3} > \frac{3}{5}$ Hungariare.	4, $\frac{P}{O} < \frac{3}{5} > \frac{1}{7}$ x
RANG I, PERMIRLIC, $\frac{CaO + MgO + FeO}{Na_2O} > \frac{7}{1}$ ...	1. *Minnesotase*	1. x	1. *Wehrlase*	1. *Cortlandtase*
Section 1, Permiric, $\frac{MgO + FeO}{CaO} > \frac{7}{1}$ ...	1. Minnesotiase	1 ...	1. Wehrliase	1. Cortlandtiase
Subrang 1, Permagnesic, $\frac{MgO}{FeO} > \frac{7}{1}$ ...	1 ...	1 ...	1. x	1. Cortlandtose
Subrang 2, Domagnesic, $\frac{MgO}{FeO} < \frac{7}{1} > \frac{5}{3}$ ...	2. Cookose	2 ...	2. Wehrlose	2. Custerose
Subrang 3, Magnesiferrous, $\frac{MgO}{FeO} < \frac{5}{3} > \frac{3}{5}$ ...	3 ...	3 ...	3 ...	3 ...
Subrang 4, Doferrous, $\frac{MgO}{FeO} < \frac{3}{5} > \frac{1}{7}$ ...	4 ...	4 ...	4 ...	4 ...
Subrang 5, Perferrous, $\frac{MgO}{FeO} < \frac{1}{7}$ ...	5 ...	5 ...	5 ...	5 ...
Section 2, Domiric, $\frac{MgO + FeO}{CaO} < \frac{7}{1} > \frac{5}{3}$ ...	...	2. x	2. x	2. x
Subrang 1, Permagnesic, $\frac{MgO}{FeO} > \frac{7}{1}$ ...	...	1. Belcherose	1. x	1 ...
Subrang 2, Domagnesic, $\frac{MgO}{FeO} < \frac{7}{1} > \frac{5}{3}$ ...	...	2. x	2. Rossweinose	2 ...
Subrang 3, Magnesiferrous, $\frac{MgO}{FeO} < \frac{5}{3} > \frac{3}{5}$ ... Subrangs 4 and 5 not represented.	...	3 ...	3 ...	3. x
Section 3, Calcimiric, $\frac{MgO + FeO}{CaO} < \frac{5}{3} > \frac{3}{5}$ ...	...	...	...	...
Subrang 1, Permagnesic, $\frac{MgO}{FeO} > \frac{7}{1}$ ...	...	...	...	...
Subrang 2, Domagnesic, $\frac{MgO}{FeO} < \frac{7}{1} > \frac{5}{3}$ ...	...	...	...	...
Subrang 3, Magnesiferrous, $\frac{MgO}{FeO} < \frac{5}{3} > \frac{3}{5}$ ... Subrangs 4 and 5 not represented.	...	...	...	...

CLASS IV, DOFEMANE, $\frac{\text{SAL}}{\text{FEM}} < \frac{3}{5} > \frac{1}{7}$. SUBCLASS I, DOFEMONE, $\frac{\text{POM}}{\text{A}} > \frac{7}{1}$.

	ORDER 2, $\frac{P, O}{M} < \frac{7}{1} > \frac{5}{3}$, SCOTARE.					ORDER 3, $\frac{P, O}{M} <$		
5, $\frac{P}{O} < \frac{1}{7}$ Pyreniare.	1, $\frac{P}{O} > \frac{7}{1}$ x	2, $\frac{P}{O} < \frac{7}{1} > \frac{5}{3}$ Paoliare.	3, $\frac{P}{O} < \frac{5}{3} > \frac{3}{5}$ Texiare.	4, $\frac{P}{O} < \frac{3}{5} > \frac{1}{7}$ x	5, $\frac{P}{O} < \frac{1}{7}$ x	1, $\frac{P}{O} > \frac{7}{1}$ Bergeniare.	2, $\frac{P}{O} < \frac{7}{1} > \frac{5}{3}$ x	3, ...
1. *Lherzase*	1. x	1. *Paolase*	1. *Texase*	1. *Casselase*	1. x	1. *Bergenase*	1. x	1...
1. Lherziase	1..............	1 Valbonniase	1. Marquettiase	1. x	1. Kalteniase	1. Bergeniase	1............	1...
1. Lherzose	....	1. Valbonnose	1.............	1. x	1............	1............	....	....
2. Argeinose	....	....	2. Marquettose	2. x	2............	2............	....	....
3............	....	....	3.............	3.............	3. Kaltenose	3. Bergenose	....	....
4............	....	....	4.............	4.............	4............	4............	....	....
5............	....	....	5.............	5.............	5............	5............	....	....
2............	2..............	2. x	2. Uvaldiase	2. Casseliase	2. x	2............	2. x	2...
1............	1..............	1.............	1. x	1. x	1............	....	1............	....
....	2..............	2. x	2. Uvaldose	2. Casselose	2. x	....	2. x	....
....	3..............	3.............	3.............	3.............	3............	....	3............	....
3. Venanziase	3. Brandbergiase	3. Paoliase	....	....	....	....	3. Avezaciase	....
1............	1..............	1.............	....	....	....	....	1............	....
2. Venanzose	2. Brandbergose	2. Paolose	....	....	....	....	2............	....
3............	3..............	3.............	....	....	....	....	3. Avezacose	....

$<\frac{5}{3}>\frac{3}{5}$, SVERIGARE.			ORDER 4, $\frac{P, O}{M}<\frac{3}{5}>\frac{1}{7}$, ADIRONDACKARE.					
$\frac{P}{O}<\frac{5}{3}>\frac{3}{5}$	4, $\frac{P}{O}<\frac{3}{5}>\frac{1}{7}$ x	5, $\frac{P}{O}<\frac{1}{7}$ Sverigiare.	Suborder	1, $\frac{H}{T}>\frac{7}{1}$	2, $\frac{H}{T}<\frac{7}{1}>\frac{5}{3}$ Adirondackore.	3, $\frac{H}{T}<\frac{5}{3}>\frac{3}{5}$ Champlainore.	4. $\frac{H}{T}<\frac{3}{5}>\frac{1}{7}$ x	5, $\frac{H}{T}<\frac{1}{7}$ ....
....	1. x	1. *Tabergase*	....	....	1. *Adirondackase*	1. *Champlainase*	1............	....
....	1............	1. Tabergiase	....	....	1. Adirondackiase	1. Champlainiase	1............	....
....	....	1............	....	....	1;............	1............	1............	....
....	....	2............	....	....	2............	2............	2............	....
....	....	3............	....	....	3............	3............	3............	....
....	....	4............	....	....	4. x	4. x	4............	....
....	....	5............	....	....	5............	5............	5............	....
....	2. x	....	....	....	....	....	....	....
....	1............	....	....	....	....	....	....	....
....	2. x	....	....	....	....	....	....	....
....	3............	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....

	ORDER 4, $\frac{P,\ O}{M} < \frac{3}{5} > \frac{1}{7}$, ADIRONDACKARE.						ORDER 5
5, $\frac{P}{O} < \frac{1}{7}$ Sverigiare.	Suborder	1, $\frac{H}{T} > \frac{7}{1}$	2, $\frac{H}{T} < \frac{7}{1} > \frac{5}{3}$ Adirondackore.	3, $\frac{H}{T} < \frac{5}{3} > \frac{3}{5}$ Champlainore.	4. $\frac{H}{T} < \frac{3}{5} > \frac{1}{7}$ x	5, $\frac{H}{T} < \frac{1}{7}$	
1. *Tabergase*	....	....	1. *Adirondackase*	1. *Champlainase*	1............	....	No analyses known.
1. Tabergiase	....	....	1. Adirondackiase	1. Champlainiase	1............	....	
1............	....	....	1;............	1............	1............	....	
2............	....	....	2............	2............	2............	....	
3............	....	....	3............	3............	3............	....	
4............	....	....	4. x	4. x	4............	....	
5............	....	....	5............	5............	5............	....	
....	....	....	....	....	....	....	
....	....	....	....	....	....	....	
....	....	....	....	....	....	....	
....	....	....	....	....	....	....	
....	....	....	....	....	....	....	
....	....	....	....	....	....	....	
....	....	....	....	....	....	....	
....	....	....	....	....	....	....	

CLASS V, PERFEMANE, $\frac{SAL}{FEM} < \frac{1}{7}$. SUB-CLASS I, PERFEMONE, $\frac{POM}{A} > \frac{7}{1}$ ·

SECTION....................	ORDER 1. $\frac{P, O}{R} > \frac{7}{1}$, MAORARE.			
	1, $\frac{P}{O} > \frac{7}{1}$ CAROLINIARE.	2, $\frac{P}{O} < \frac{7}{1} > \frac{5}{3}$ MARYLANDIARE	3, $\frac{P}{O} < \frac{5}{3} > \frac{3}{5}$	4, $\frac{P}{O} < \frac{3}{5} >$ X
RANG 1, PERMIRLIC, $\frac{CaO + MgO + FeO}{Na_2O} > \frac{7}{1}$............	1. *Websterase*	1. *Baltimorase*	1.............	1. x
Section 1, Permiric, $\frac{MgO + FeO}{CaO} > \frac{7}{1}$..................	1. Mariciase	1. x	1.............	1. x
Subrang 1, Permagnesic, $\frac{MgO}{FeO} > \frac{7}{1}$................	1. Maricose	1. x	1.............	1. x
Subrang 2, Domagnesic, $\frac{MgO}{FeO} < \frac{7}{1} > \frac{5}{3}$.............	2............	2.............	2.............	2. x
Subrang 3, Magnesiferrous, $\frac{MgO}{FeO} < \frac{5}{3} > \frac{3}{5}$..........	3............	3.............	3.............	3..........
Subrang 4, Doferrous, $\frac{MgO}{FeO} < \frac{3}{5} > \frac{1}{7}$................	4............	4.............	4.............	4..........
Subrang 5, Perferrous, $\frac{MgO}{FeO} < \frac{1}{7}$..................	5............	5.............	5.............	5..........
Section 2, Domiric, $\frac{MgO + FeO}{CaO} < \frac{7}{1} > \frac{5}{3}$...............	2. Websteriase	2. Baltimoriase	....	....
Subrang 1, Permagnesic, $\frac{MgO}{FeO} > \frac{7}{1}$................	1. Websterose	1. x	....	....
Subrang 2, Domagnesic, $< \frac{7}{1} > \frac{5}{3}$..................	2. Cecilose	2. Baltimorose	....	....
Subrangs 3, 4, and 5 not represented..............	3............	3.............	....	....

Other orders of Class V not represented by analyses.

LASS V, PERFEMANE, $\frac{SAL}{FEM} < \frac{1}{7}$. SUB-CLASS I, PERFEMONE, $\frac{POM}{A} > \frac{7}{1}$.

	ORDER 1. $\frac{P, O}{R} > \frac{7}{1}$, MAORARE.				
SECTION....................	1, $\frac{P}{O} > \frac{7}{1}$ CAROLINIARE.	2, $\frac{P}{O} < \frac{7}{1} > \frac{5}{3}$ MARYLANDIARE	3, $\frac{P}{O} < \frac{5}{3} > \frac{3}{5}$	4, $\frac{P}{O} < \frac{3}{5} > \frac{1}{7}$ X	5, $\frac{P}{O} < \frac{1}{7}$ MAORIARE.
$\frac{CaO + MgO + FeO}{Na_2O} > \frac{7}{1}$............	1. *Websterase*	1. *Baltimorase*	1............	1. x	1. *Dunase*
$\frac{MgO + FeO}{CaO} > \frac{7}{1}$..................	1. Mariciase	1. x	1............	1. x	1. Duniase
gnesic, $\frac{MgO}{FeO} > \frac{7}{1}$................	1. Maricose	1. x	1............	1. x	1. Dunose
gnesic, $\frac{MgO}{FeO} < \frac{7}{1} > \frac{5}{3}$...............	2............	2............	2............	2. x	2............
esiferrous, $\frac{MgO}{FeO} < \frac{5}{3} > \frac{3}{5}$..........	3............	3............	3............	3............	3............
ous, $\frac{MgO}{FeO} < \frac{3}{5} > \frac{1}{7}$..............	4............	4............	4............	4............	4............
rous, $\frac{MgO}{FeO} < \frac{1}{7}$................	5............	5............	5............	5............	5............
$\frac{MgO + FeO}{CaO} < \frac{7}{1} > \frac{5}{3}$..............	2. Websteriase	2. Baltimoriase	....	....	....
gnesic, $\frac{MgO}{FeO} > \frac{7}{1}$................	1. Websterose	1. x	....	....	....
gnesic, $< \frac{7}{1} > \frac{5}{3}$..................	2. Cecilose	2. Baltimorose	....	....	....
5 not represented...............	3............	3............	....	....	....

Other orders of Class V not represented by analyses.

tion and the actual, there is obviously no need of mentioning details of the actual mineral composition, since this is fully expressed by the norm. To indicate this mode it is only necessary to use the word *normative*, before the magmatic name and connected with a hyphen.

As has been already remarked, though all the various possible combinations of the feldspar molecules are regarded as standard, yet it will often be found needful to indicate the special feldspars actually crystallized. In this case, since the albite most often crystallizes with the anorthite molecule, forming a soda-lime plagioclase, and since the character of this will condition that of the alkali-feldspar, it will in general only be necessary to name the soda-lime plagioclase which is present. If, however, it is desirable to indicate the presence of microline or anorthoclase, this can also be done.

To express the extent to which the mode of a rock differs from the norm it is necessary to state the kinds of minerals which are different as well as the amount to which they have been developed.

It is proposed to use the names of the minerals in question as adjective qualifiers of the magmatic name, as has been the custom with such names as mica-diorite, and to express their quantitative relations by means of prefixes or suffixes, or by the order of their arrangement when several mineral names are employed.

Owing to the interdependence of the minerals in any rock on each other and on the chemical composition of the magma, it is evident that, given the norm of a rock, which is involved in its magma name, it is only necessary to state the presence and amount of certain minerals developed, which are not in accord with the norm, in order to determine the modifications of the standard minerals consequent upon the development of these particular ones.

And since such modifications take place in all degrees, from the slightest possible change to the greatest possible, it is necessary to recognize in a systematic manner differences of degree.

Those already suggested in the chapter on classification with respect to actual mineral classification are two: (1) modifications of the norm, which are so slight as not to interfere with the classification of the rock directly from the mode; and (2) modifications of the norm so considerable that the rock cannot be classified directly from the mode without readjustment of the molecules in accordance with the method of calculation for obtaining the norm.

In other words, we may distinguish (1) variations among the actual minerals which fall within the limits possible in rocks with normative modes, and (2) those variations among the minerals which cause the rock to possess an abnormative mode.

1. Minerals of the first kind may be termed *varietal* minerals. They may be defined as minerals whose presence serves to characterize and distinguish different rocks of one magma unit, but whose amount is so small that they do not affect the character of the mode as normative or abnormative. Varietal minerals include: standard minerals whose presence is not indicated by the general expression of the norm, that is, the magmatic name, though an exact statement of the norm would recognize their presence; or they may include any of the non-standard minerals. For example: small amounts of quartz or feldspathoid in rocks of Order 5, in Classes I, II, III; or small amounts of hornblende and biotite, etc.

It is proposed to express in the nomenclature the presence of varietal minerals in the rock by adding to the name of the mineral the suffix *-ic*. When it is necessary to use several varietal qualifiers at one time the mineral names are to be connected by hyphens and the suffix applied to the last, as hornblende-biotitic alsbachose.

2. Minerals of the second kind, whose presence and amounts are such as to produce abnormative modes are called *critical* minerals, as already mentioned. They are for the most part alferric, but may be salic or femic, according to the mode of the rock.

It is proposed to express the presence of a critical mineral in a rock by using the name of the mineral without modification, compounding it with the magmatic name by means of a hyphen.

In case there are several critical minerals present, their names are to be used in such order that the most abundant stands nearest to the magmatic name, and the least abundant the farthest from it.

It may become desirable when the number of mineral names is considerable to abbreviate and compound them in the manner suggested by Chamberlin,[1] and Jevons.[2]

It is to be remarked that it will not always be necessary to state the exact character or species of the critical mineral. It will often merely be necessary to mention the mineral group, whether augite, hornblende, mica, garnet, etc. This is because experience shows that in a magma of a given character the augite or hornblende formed will in general be of a more or less constant character. Thus in highly calcic magmas the augite will in general be of one kind, in sodic magmas of another, and in magnesic magmas of another.

The critical minerals, especially the alferric, may be developed within wide limits, which in the more femic Classes may be illustrated by three rocks of the dosodic Subrang of the alkalicalcic Rang of the Order portugare, of the salfemane Class. In this we find the hornblendite of Gran, which consists entirely of an alkalic hornblende, with no visible salic or femic minerals. Here also belongs the olivine-gabbro-diabase of the same locality, in which much of the feldspar has actually crystallized as such, and in which the hornblende consequently is less alkalic, and augite is present. We also find here a nephelite-basanite of Colfax county, New Mexico, in which the actual composition corresponds quite closely with the norm. The chemical analyses of these three rocks show their chemical likeness.

In the first case all the possible alferric mineral has been formed, as hornblende, in the second case only a part, approxi-

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[1] *Geology of Wisconsin*, Vol. I. pp. 30–40. Madison, 1883.

[2] *Geol. Mag.*, Vol. VIII, p. 304, 1901.

No.	1.	2.	3.	No.	1.	2.	3.
SiO_2	37.90	43.65	42.35	P_2O_5	tr	tr	.99
Al_2O_3	13.17	11.48	12.29	SO_3	.....	.....	.05
Fe_2O_3	8.83	6.32	3.89	S	.....	.....	tr
FeO	8.37	8.00	7.05	Cr_2O_3	.....	.....	.10
MgO	9.50	7.92	13.09	V_2O_3	.....	.....	.04
CaO	10.75	14.00	12.49	NiO	.....	.....	.03
Na_2O	2.35	2.28	2.74	MnO	.....	.....	.21
K_2O	2.12	1.51	1.04	BaO	.....	.....	.10
H_2O+	1.40	1.00	1.50	SrO	.....	.....	.09
H_2O-	.....		.32	Li_2O	.....	.....	tr
CO_2	.....	tr	.....				
TiO_2	5.30	4.00	1.82		99.69	100.16	100.19

No. 1. Hornblendite, Brandberget, Gran, Norway. V. Schmelck, anal.; BRÖGGER, *Erupt. Gest. Kryst. Geb.*, Vol. III (1899), p. 93.

No. 2. Olivine-gabbro-diabase, Brandberget, Gran, Norway. V. Schmelck, anal.; BRÖGGER, *Quart. Jour. Geol. Soc.*, Vol. L (1894), p. 19.

No. 3. Nephelite-basanite, Ciruella, Colfax Co., N. M. W. F. Hillebrand, anal.; *Bull. 168, U. S. G. S.* (1900), p. 171.

mately half, chiefly as augite, while in the last very little such modification of the norm has taken place.

It is possible to devise a method of expressing in the nomenclature relative amounts of critical minerals for a comparatively simple case such as the one just given. But the problem is more complicated when several of these minerals, as hornblende, augite, and mica, are present at the same time, which frequently happens. The development of one modifies the maximum that may be attained by another, so that the expression of the relative degrees of development of each is a function of the others, and an exact expression in the nomenclature becomes extremely difficult, and is perhaps impracticable.

It will often be found useful to be able to indicate the presence of certain minerals in rock groups, when the relative amount which determines the Order, or lesser division, is not known or needful for the purpose in view. Thus we may want to speak of the persalanes or the dosalanes which carry quartz or nephelite, without specifying the relative amounts of these, *i. e.*, without making use of the ordinal divisions. In these cases it is proposed that the name of the mineral be given followed by the word *-bearing*. So the cases just mentioned would be quartz-bearing or nephelite-bearing persalane and dosalane respectively. Such names indicate only that the rocks belong to these Classes and carry quartz or nephelite, with no implication of their other characters.

TEXTURE.

As already explained, the texture of a rock is to be expressed in the nomenclature by a qualifying term applied to the name of the magmatic unit, and connected with it by a hyphen.

There are now in use terms expressing some of the commonest and most characteristic textural features of igneous rocks. It is proposed to use these in their present form, or to modify them by abbreviation in some cases with the addition of syllables indicating the degree of granularity. The syllable *-o* is added to indicate that the texture is recognizable megascopically ; *-i* is added when it is microscopic. For example:

Granitic = xenomorphic and hypautomorphic granular ; *grano* = megascopically granitic, megagranitic ; *grani* = microscopically granitic, microgranitic.

Trachytic = panautomorphic with tabular feldspars ; *tracho* = megascopically trachytic, megatrachytic ; *trachi* = microscopically trachytic, microtrachytic.

Graphic = pegmatitic = granophyre in the Rosenbusch sense ; *grapho* = megagraphic ; *graphi* = micrographic.

Poikilitic ; poikilo = megapoikilitic ; *poikili* = micropoikilitic.

Ophitic ; ophito = megophitic ; *ophiti* = microphitic.

Felsitic = aphanitic ; *felso* = megafelsitic ; *felsi* = microfelsitic, microscopically homogeneous, but not isotropic glass.

Vitreous ; vitro = megascopically vitreous ; *vitri* = microscopically vitreous.

Spherulitic ; sphero = megaspherulitic ; *spheri* = microspherulitic.

Porphyritic ; phyro = megaporphyritic ; *phyri* = microporphyritic, that is, the phenocrysts are not megascopically notable, or are quite insignificant.

With the term *phyr* may be combined one indicating the texture of the groundmass as follows :

Porphyritic granitic ; granophyro = megagranitic, megaporphyritic ;

graniphyro = microgranitic, megaporphyritic (granophyric in the Vogelsang sense); *graniphyri* = microgranitic, microporphyritic.

Porphyritic graphic; graphophyro = megagraphic, megaporphyritic; *graphiphyro* = micrographic, megaporphyritic; *graphiphyri* = micrographic, microporphyritic.

Porphyritic felsitic; felsophyro = megascopically felsitic and porphyritic; *felsophyri* = megafelsitic, microporphyritic; *felsiphyri* = microscopically felsitic and porphyritic.

Porphyritic vitreous; vitrophyro, vitrophyri, vitriphyro, vitriphyri.

Porphyritic poikilitic; poikilophyro, poikiliphyro, etc.

Porphyritic ophitic; ophitophyro, ophitiphyro, etc.

Aphyro = megascopically non-porphyritic, or *aphyric.*

Aphyri = microscopically non-porphyritic, or *aphyric.*

Salphyro = megascopically porphyritic with salic phenocrysts, *salphyric.*

Femphyro = megascopically porphyritic with femic phenocrysts, *femphyric.*

Alferphyro = megascopically porphyritic with alferric phenocrysts, *alferphyric.*

Salfemphyric, alfersalphyric, alferfemphyric etc.

From the foregoing statement we may summarize the method of formulating the nomenclature here proposed as follows:

1. The *magmatic name*, of whatever division is to be indicated, which is formed by the use of the locality root and appropriate termination, stands as the basis of nomenclature, and is the substantive part of the terminology. This is because the fundamental character of igneous rocks is the chemical composition of the magma, which persists whatever be the mineral development or the texture determined by conditions obtaining during solidification.

2. According to the information at hand, or to be conveyed, the *magmatic name* must be selected which represents the Class, Order, or other division to which the rock belongs. And this name may be qualified by mineral and textural adjectives. Thus it is possible to indicate the Class of a rock, when first observed in the field, and to describe its chararteristic mineral components, and its texture. If the relative proportions of its dominant minerals, salic or femic, can be readily determined, the magmatic name for the *Order* can be used. Subsequently more

specific magmatic names can be given to it. In each of these cases the critical mineral and the texture can be indicated by the same qualifying terms, or more precise ones if needed.

In this respect this system possesses a distinct advantage over former ones, in which no attempt has been made to indicate in the nomenclature the degree of exactness with which the rock is known or is to be described.

3. To indicate the actual mineral character of a rock when its *magmatic name* is given it is only necessary to express either the fact that it is standard or the departure from the norm by mentioning those *critical* minerals whose presence induces changes in the norm, or those *varietal* minerals which may be present. When such exactness is desired:

a) If the rock possesses a *normative mode* the actual mineral composition is expressed by using the word normative before the magmatic name.

b) If the rock does not possess a normative mode and it is desired to indicate the *critical* minerals present, it is proposed that such mineral qualifiers be used in some cases without introducing quantitative modifications. These mineral qualifiers may be used as full names attached to the magmatic name by a hyphen, as is the present practice, or they may be abbreviated and compounded.

c) It is suggested that the presence of small amounts of important minerals be indicated by adding the suffix *-ic* to the mineral name.

4. The texture is to be indicated by adjectives expressing the fabric, the crystallinity, and the granularity, and may be the terms in common use, those suggested above, or abbreviations of these.

5. Either mineral or textural qualifiers may be placed next to the magmatic name according to the emphasis to be given them, it being generally understood that the term nearest the magmatic name carries the strongest emphasis; the magmatic name coming last. The same rule is to be applied to the arrangement of several mineral qualifiers, that nearest the magmatic name is to be considered the most important.

Examples.—To illustrate the methods proposed, the following examples may be given, especial stress being laid on the possibility of expressing the exact amount of knowledge which is at hand or is to be conveyed.

1. The typical monzonite of Brögger, from Monzoni—an evenly granular, phaneric rock, composed, as seen in the field, of dominant feldspars, with only traces of quartz, considerable pyroxene, hornblende, and less biotite, with insignificant amounts of magnetite and apatite.

From the analysis by V. Schmelck[1] the following norm is calculated :

Orthoclase	26.1		68.1
Albite	26.2		
Anorthite	15.8		
Diopside	18.4	24.5	31.9
Hypersthene	3.3		
Olivine	2.8		
Magnetite	5.3	6.1	
Ilmenite	0.8		
Apatite	1.3	1.3	
			100.0

The rock belongs, therefore, to Class II, the *dosalanes*, with salic minerals dominant over femic, and this is evident even in the field.

Since, among the dominant salic minerals, neither quartz nor feldspathoids (lenads) are present, it belongs to the fifth Order, and is consequently, *germanare*. This, likewise, can be determined from the megascopic examination.

On referring to the analysis it is seen that the alkalies are to lime in normative anorthite as the ratio $0.097:0.057=1.70$. The rock, therefore, belongs to the second Rang, the domalkalic, to which we have given the name of *monzonase*. This, and the following points, could not be determined in the field.

As $K_2O':Na_2O' :: 0.047:0.050$, the two are in nearly equal amount, and the Subrang is thus the third, sodipotassic, which we have called *monzonose*.

We have thus characterized the rock completely, as far as the dominant minerals are concerned. Taking up the subordinate ones, we see from the norm that the pyroxenes and olivine are together dominant over the non-silicates, magnetite and ilmenite, the apatite being in negligible amount. The Grad is therefore the second, and this might be called *monzonate*.

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[1] W. C. Brögger, *Eruptivgest. Kristianiageb.* Vol. II, p. 24, 1895.

Coming to Subgrad, we have to deal with the chemical character of the femic minerals. This is $(\mathrm{Mg, Fe})\mathrm{O}:\mathrm{CaO}'' :: 0.160 : 0.094 = 1.702$. The Subgrad is the second, domiric, and this might be named *monzonote*.

Taking up next the mode and texture, it has been seen that the mode is normative as far as the salic minerals are concerned, but that hornblende, with a little biotite, largely replaces the normative femic minerals. Hornblende is therefore the *critical* mineral and biotite the *varietal*. The texture is simply a normal granitic one and rather coarse, for which we use the term *grano*.

In the field, then, the rock would be referred to either its Class, as *biotitic hornblende-grano-dosalane*, or its Order, as *biotitic hornblende-germanare*, or as a *grano-hornblende-germanare*, if we wished to disregard the small amount of biotite and emphasize the hornblende content.

Further study with the microscope and in the laboratory would allow us to speak of the rock as *grano-hornblende-monzonase*, or *biotitic hornblende-grano-monzonose*, according to what information we wished to convey.

The augite-latite of the Dardanelle Flow, in Tuolumne county, California,[1] which belongs to the same Subrang, would be spoken of as *normative phyro-monzonose*, since the augite is almost wholly diopside. Since, however, in the norm of this rock pyroxene and magnetite are present in equal amounts, it would belong to the third Grad, which might be called *dardanellate*.

Similarly, confining ourselves to the same Subrang, the olivine-trachyte of the Arso, in Ischia, would be *olivinic-phyro-monzonose*, the gauteite of Hibsch[2], a *hornblende-trachiphyro-mon-*

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[1] F. L. Ransome, *A. J. S.*, Vol. V, p. 363, 1898.

[2] J. E. Hibsch, *T. M. P. M.*, Vol. XVII, p. 84, 1897.

zonose, and the mica-basalt of Santa Maria Basin, Arizona,[1] a *felsophyro-biotite-monzonose.* A glassy facies of any of these, with hornblende phenocrysts, for example, would be *hornblende-vitro-monzonose.* A pure glass of this composition would be simply a *vitro-monzonose*, or *aphyrovitro-monzonose;* if microlitic it would be a *phyrivitro-monzonose.*

To take another example, the normal, lithoidal, micro-spherulitic and porphyritic rhyolite of the Yellowstone National Park is *spheriphyro-alaskose*, which is a very concise expression for a rock that is microscopically spherulitic, megascopically porphyritic, having the chemical composition of a rock whose norm consists of extreme salic minerals, of which quartz and feldspar are nearly equal, the feldspars extremely alkalic, and soda and potash in nearly equal proportions.

An example of intermediate rock is to be found in the granite of Butte, Mont., whose composition is discussed at length in connection with the calculation of norm and mode. This rock belongs near the border line between Classes I and II, and the rock from Walkerville Station, Butte, has $\frac{\text{sal}}{\text{fem}} = 7.14$. It is a persalane near dosalane, and may be called dosalane-persalane, which contracts to do-persalane.

The Order is quardofelic,

$$\frac{F}{Q} = 3.4, < \frac{7}{1} > \frac{5}{3};$$

it is britannare (Class I) near austrare (Class II), or austrare britannare. The Rang is alcalicalcic,

$$\frac{K_2O' + Na_2O'}{CaO'} = 1.38, < \frac{5}{3} > \frac{3}{5};$$

it is coloradase (Class I) near tonalase (Class II), or tonalase-coloradase. The Subrang is sodipotassic,

$$\frac{K_2O'}{Na_2O'} = 1, < \frac{5}{3} > \frac{3}{5};$$

it is amiatose (Class I) near harzose (Class II) or harzose-amiatose.

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[1] *Bull, 148 U. S. G. S.*, p. 187 (B, C, D), 1897.

TYPE AND HABIT.—It is clearly obvious that if great precision or completeness be desired, so that both mineralogical and textural qualifiers are used, the polynomial name resulting will be of considerable length, comparable to such present names as quartz-hornblende-biotite-diorite-porphyry. This will probably not be as great a practical difficulty or inconvenience as may appear at first sight, since after a given rock has been described and named in full in any given article, it may be referred to subsequently by its magmatic name alone, or by this in conjunction with a textural or modal term, according to circumstances.

However, since the same or similar assemblages of modal and textural characters are found in many localities it will be as well to be able to express these concisely. This is, after all, what is accomplished by many of the names in the present systems of nomenclature, although it has not been done systematically. Thus the names granite, rhyolite, tinguaite, laurvikite, etc., convey primarily an idea of the qualitative mineral composition and the texture of the respective rocks, with a very rough one of the magmatic character.

It is to be noted that there are two degrees of similarity among rocks which can be easily recognized and made use of. One is almost complete *identity*, the other a *general resemblance* which suggests identity.

Type.—For the first of these, *identity* or almost complete identity, we propose the use of the term *type*. Rocks of the same type are identical in norm, mode, and texture, or almost completely so. They are of the same grain, have the same fabric, the same actual mineral composition, and are so much alike that they may be mistaken for one another or might have been parts of one rock body. Many examples of such close similarity are familiar to all petrographers.

The particular modal and textural features which characterize rocks of a given type are to be expressed by a single adjective word, composed of a root derived from a geographical locality in which a rock of the type occurs, but not already employed to designate a magmatic unit, and the termination *-al*.

Habit.—In order to express the fact that one rock resembles in general appearance another well-known rock by exhibiting some of its characteristic features without being identical in composition or mode we propose to use the term *habit,* formerly in constant requisition among petrographers. The features of a rock characterizing its habit may be both textural and mineral. For example: one rock may be porphyritic, with a dark-colored, aphanitic groundmass, and the phenocrysts rhombic feldspars. Another rock may have these features, but belong to a chemically different magma. The two may be said to have the same habit. And the second may be sufficiently described by giving its proper magmatic name qualified by an adjective indicating the habit of the first rock.

To accomplish this we propose that the habit of a rock be expressed by a word formed similarly to one expressing type but with the termination *-oid.* The root of the word is to be taken from some geographical locality. It may be the same as one used for a type, since a common type rock may be one whose habit will often be used in describing another, less common, rock.

Thus a particular form of rock belonging to the Order russare, of the persalanes, may constitute the *tingual type*, with definite norm, mode, and texture; while a somewhat similarly appearing rock belonging to the Order norgare, of the dosalane Class may possess a *tinguoid habit.*

The habital qualifier may be applied to a magmatic name of any systematic division, since it does not specify the composition of a rock. Thus we may describe a rock as a tinguoid dosalane, or a tinguoid norgare, a tinguoid laurdalase, etc. There may be tinguoid persalanes and salfemanes.

It is obvious that, with the use of types and habits, the nomenclature will tend to become binomial, and hence much more easy of application than in the present systems, or in the full one proposed here. It will, however, differ radically from the binomial nomenclature in use in the organic sciences, since the habital qualifier will not correspond to the specific terms of these, applicable only to the generic name, but will be applicable to any division of the classification from Class to Subgrad.

ROCK NAMES FOR GENERAL FIELD USE.

It is obvious that a considerable part of the system of classification and nomenclature here proposed can only be applied upon microscopical or chemical investigation. This is equally true of a large part of that in present use. There are many distinctions based on characters that cannot be observed with the unaided eye, such as differences among the plagioclase feldspars, and the mineral composition of aphanitic rocks.

It is also clear that the system demands a more detailed knowledge of rocks than many geologists, mining engineers, and others interested in geology, may care to acquire. This is a natural consequence of the advance in petrological science, which requires a corresponding advance in specialization and in petrographical classification and nomenclature.

For these reasons, which might be elaborated at considerable length, we are convinced of the need of general petrographical terms which will be serviceable in the field work of the petrologist, and which will be of use to the general geologist and to those who may not be able to carry on microscopical and chemical investigation.

Such general terms should be based on megascopic characters of the rocks and should be limited to such characters. Their application should be purely objective and everything of a subjective nature should be eliminated. It follows from this that such terms cannot be correlated with those used in the systematic nomenclature based on chemical and microscopical properties. They must be understood to have a totally different scope, and to indicate no more than the general megascopic characters with which they are connoted.

The attitude of the person using such terms is the same as that of geologists who studied rocks before the introduction of the microscope, and most of the distinctive features exhibited megascopically by igneous rocks were well known and appropriately named by the early geologists, and most of the terms used by them are in use at the present time, though their application has been variously modified by repeated redefinition.

We recommend that those terms which are needed for general field purposes, and are to be based on purely megascopic characters, be selected from the terms originally proposed by the founders of geology, and be given their original significance so far as possible, with only such modifications as a somewhat more systematic treatment of the matter may suggest.

When all igneous rocks are considered with reference to their megascopic characters their most generally recognizable features appear to be their *texture* and *color*, and in some cases, and to various degrees, their *mineral constituents*.

If we attempt to group them according to texture we find them falling into three large divisions:

1. Those whose mineral components can be seen with the unaided eye.

2. Those whose mineral components cannot all be seen with the unaided eye, and that are composed of a greater or less amount of lithoidal material not resolvable into its component parts.

3. Those with vitreous luster in the whole or a part of the mass.

The first have been called by Hauy phanerogène, and may be termed *phanerites*.

The second have been called by d'Aubuisson (1819) *aphanites*, a name which cannot be improved upon.

The third have been long known as volcanic glasses—*obsidian*, *pitchstone*, etc.

All phanerites, whether igneous or metamorphic, massive or schistose, were at an earlier time called *granite*. But at the beginning of the last century a number of kinds of phanerocrystalline (phaneric) rocks were recognized, the distinctions being based upon the minerals that could be identified megascopically. These minerals are: quartz, feldspar, leucite, nephelite, mica, hornblende, augite, the iron orès, etc. It is to be remembered that there were no specific distinctions among the feldspars. It is equally true at this day that no specific distinctions can be made with the unaided eye among the lime-soda-feldspars, and that albite, oligoclase, andesine, and labradorite cannot be identified as such without optical or chemical tests. It follows from this that phaneric rocks cannot be classed by purely megascopical means as having alkali-feldspars, or more calcic feldspars. We must not attempt to subdivide these rocks on the basis of characters not recognizable megascopically and must content ourselves with employing mineral groups, such as feldspar, mica, amphibole (hornblende), pyroxene, etc., as bases for their field designation.

For these reasons we suggest the following use of familiar terms when rocks are to be named on a purely megascopical basis.

I. PHANERITES—phanerocrystalline (phaneric) rocks.

1. *Granite*—all granular igneous rock composed of dominant quartz and feldspar, of any kind, with mica, hornblende, or other minerals in subordinate amount. This is the granite of Werner, von Leonhard, and other early geologists, and will include what is now termed granite, granodiorite, tonalite, and most quartz-diorites. It will embrace all light-colored, granular rocks with dominant feldspar and a noticeable amount of quartz. It will include the quartz- (hornblende) -syenites of earlier geologists.

2. *Syenite*—all granular igneous rocks composed of dominant feldspars, of any kind, with subordinate amounts of mica, hornblende, pyroxene, or other minerals, and without noticeable amount of quartz. This is the syenite of Werner, von Leonhard, and others, with slight modification, and will include modern syenite, anorthosite, and the more feldspathic monzonites, diorites, and gabbros. If it is desirable to distinguish the plagioclase rocks when recognizable, such as the coarse-grained anorthosites, they may be called plagioclase-syenites, or anorthosites.

3. *Diorite*—all granular igneous rocks with dominant hornblende and subordinate feldspar of any kind. This is the

diorite of d'Aubuisson (1819) as defined by von Leonhard (1823). It will include the less feldspathic diorites and hornblende-gabbros.

4. *Gabbro*—all granular igneous rocks with dominant pyroxene and subordinate feldspar of any kind, with or without hornblende and mica. Essentially the gabbro of von Leonhard. Since it is not possible to identify pyroxene as distinct from hornblende in many cases, megascopically, it will probably happen that all of those rocks which can be clearly seen to contain dominant hornblende will be called diorite, and all doubtful ones will be grouped with the distinctly pyroxenic gabbros. These rocks will include the less feldspathic gabbros and norites, and some diorites.

5. *Peridotite, pyroxenite,* and *hornblendite*—all granular igneous rocks composed almost completely of olivine, pyroxene, or hornblende, in variable proportions, with little or no feldspar. These names are to be applied as at present.

Other names in common use, which can be applied without confusion upon the basis of purely megascopical determination, may be used.

II. APHANITES—lithoidal, aphanitic rocks. These may be non-porphyritic or porphyritic, the aphanitic character being confined to the groundmass.

A. *Non-porphyritic forms,* having no recognizable mineral constituents, must be subdivided, if at all, upon the basis of color, luster, or other physical properties. The early distinctions were in reality on a basis of color, and were two:

1. *Felsite* (Gerhard, 1814), Phonolite (Klaproth, 1801), Petrosilex of the French geologists. *Felsite* includes all aphanitic igneous rocks that are non-porphyritic and are light-colored, in various tones, and with various lusters other than vitreous. They include lithoidite (von Richthoven, 1860), or lithoidal rhyolite, non-porphyritic trachite, and phonolite, and the lighter colored non-porphyritic andesites, latites, etc.

2. *Basalt*—all dark-colored, aphanitic, igneous rocks without phenocrysts. This will include the dark-colored andesites, non-

porphyritic basalts, diabases, and other lavas known by a number of names, which before the classic studies of Zirkel were grouped togther as basalt.

B. *Porphyry*—porphyritic forms may all be embraced within the general term of *porphyry*. They may be separated on a basis of color to correspond to the divisions above mentioned into two groups.

1. *Leucophyre* (Gümbel, 1874) and
2. *Melaphyre* (Brongniart, 1813).

Gümbel applied the term leucophyre to certain altered diabases of light color, which would not be included within the group here proposed, but the term was applied to altered rocks and has never been in general use, and may advantageously be redefined.

Leucophyres would include all porphyritic, aphanitic, igneous rocks, with light-colored groundmass, and with phenocrysts of any kind.

Melaphyres would include all porphyritic, aphanitic igneous rocks with dark-colored groundmass, and with phenocrysts of any kind.

According to the kinds of phenocrysts which may be identified megascopically these rocks may be named without reference to the color of the groundmass as:

Quartz-porphyry or *quartzophyre*.

Feldspar-porphyry or *feldsparphyre*, but not felsophyre, since this name is in common use for a porphyry with felsitic groundmass.

Hornblende-porphyry or *hornblendophyre*.

Mica-porphyry or *micaphyre*.

Augite porphyry or *augitophyre* (von Buch, 1824).

Olivine-porphyry or *olivinophyre* (Vogelsang, 1872).

If it is intended to indicate the color of the groundmass as light or dark, we may use the terms:

Quartz-leucophyre or *quartz-melaphyre*.

Feldspar-leucophyre or *feldspar-melaphyre*.

Hornblende-leucophyre or *hornblende-melaphyre*.

It is to be remembered that these terms leucophyre and melaphyre imply nothing as to the composition of the groundmass. They strictly indicate nothing but its color.

III. THE GLASSES—glassy rocks have been classified on a basis of luster and texture as follows:

1. *Obsidian*—vitreous rock of any color, usually black, often red, less often brown and greenish.

2. *Pitchstone*—resinous and less lustrous than obsidian, and consequently lighter colored.

3. *Perlite*—glassy rock with perlitic texture produced by small spheroidal fractures.

4. *Pumice*—highly vesicular glass, usually white or very light-colored.

Each of these varieties may be non-porphyritic or porphyritic. The latter may be called

Vitrophyre (Vogelsang, 1867) and may be qualified by mineral terms indicating the character of the prominent phenocrysts, yielding *quartz-vitrophyre*, *feldspar-vitrophyre*, etc. They may also be called porphyritic obsidian, pitchstone, perlite, or pumice.

PART III. METHODS OF CALCULATION.

In order to obtain concordant results in all cases in the determination of the kinds and amounts of standard minerals that correspond to a magma of any given chemical composition, a uniform method of calculation is necessary. This calculation may be made either from the chemical analysis of the rock or from the quantitative estimate of the minerals actually present in it.

The calculation of *standard minerals* belonging to the salic and femic groups, rather than that of the actual minerals which may be present in the rock, is warranted not only by the fact of the variable possibilities of crystallization in one magma, but because of the difficulty of determining the quantity and chemical character of the minerals actually present in many rocks. It is further warranted because of the impossibility of determining the minerals in a great number of rocks in which they are too small, and because of the incomplete crystallization of all more or less glassy rocks.

The variability in the development and chemical composition of the *alferric minerals* justifies us in treating them as combinations by readjustment of salic and femic molecules. Their chemico-mineralogical relations and the method of calculating their proportions will be stated later on.

The method of calculation adopted is based upon a number of commonly observed chemico-mineralogical relations that obtain in the rock-making minerals, which may be stated as follows:

CHEMICAL RELATIONS AMONG SALIC MINERALS.—1. The constant relation between the molecules of Al_2O_3 and K_2O and Na_2O in orthoclase and albite, leucite and nephelite ($Al_2O_3 : K_2O + Na_2O :: 1 : 1$).

2. The somewhat similar relation between these constituents in the sodalites, where the soda is slightly in excess. The ratio in sodalite is $Al_2O_3 + \frac{1}{3}Cl_2 : Na_2O + \frac{1}{3}Na_2O :: 1 : 1$; in noselite it is $Al_2O_3 + \frac{1}{2}SO_3 : Na_2O + \frac{1}{2}Na_2O :: 1 : 1$.

3. The constant relation between Al_2O_3 and CaO in the anorthite molecule ($Al_2O_3 : CaO :: 1 : 1$).

4. The development of corundum under favorable conditions in rocks with excess of Al_2O_3 over K_2O, Na_2O, and CaO.

5. The relation between the development of alkali-feldspar (polysilicates) and of feldspathoids (meta- and ortho-silicates) and the available silica in the magma, so that free silica (quartz) does not crystallize together with leucite and nephelite.

6. The stronger affinity of Al_2O_3 for K_2O and Na_2O than for CaO, Al_2O_3 forming alkali-feldspars and feldspathoids (lenads) in preference to anorthite.

7. The constant ratio between ZrO_2 and SiO_2 in zircon, $ZrO_2 : SiO_2 :: 1 : 1$.

CHEMICAL RELATIONS AMONG FEMIC MINERALS.—1. The constant relation between Fe_2O_3 and Na_2O in the acmite molecule ($Fe_2O_3 : Na_2O :: 1 : 1$).

2. The general fact that this molecule is developed in magmas when K_2O and Na_2O are in excess of Al_2O_3.

3. The constant relation between Fe_2O_3 and FeO in magnetite (Fe_2O_3 : FeO : : 1 : 1).

4. The relation between FeO and TiO_2 in ilmenite (FeO : TiO_2 : : 1 : 1).

5. The relation of TiO_2 and CaO in titanite and in perofskite (TiO_2 : CaO :: 1 : 1).

6. The development of the titano-silicate, titanite, in the more siliceous rocks, and of the non-siliceous perofskite in its place in the less siliceous ones.

7. The constant relation of P_2O_5 to CaO in apatite (P_2O_5 : CaO : : 1 : 3.33).

8. The relation of CaO and (Mg,Fe)O in monoclinic pyroxene, diopside (CaO : (Mg,Fe)O : : 1 : 1).

9. The occurrence of (Mg,Fe)O both as metasilicate or orthosilicate, in hypersthene and olivine.

10. The frequent, but not invariable, relation between (Mg,Fe)O and available silica, whereby metasilicate, hypersthene, forms instead of orthosilicate, olivine, with sufficient available silica.

11. The occasional occurrence of a sodium metasilicate molecule, $Na_2O.SiO_2$, which enters into arfvedsonite in rocks in which K_2O and Na_2O are in excess of Al_2O_3 and Fe_2O_3.

12. The fact that, apart from apatite, the only common non-silico-aluminous, primary rock-making minerals are magnetite and ilmenite; the iron being the only element of the important ones which in rocks can crystallize without SiO_2 or Al_2O_3.

13. Finally the common occurrence of SiO_2, CaO and Na_2O in minerals of both the salic and femic groups, and their resulting interdependence.

CALCULATION OF THE NORM.

The method adopted by us of calculating the standard mineral composition is as follows:

1. Determine the molecular proportions of the chemical components of a rock as expressed by the complete analysis, by dividing the percentage weights of each component by its molecular weight.

2. Before undertaking the distribution of the chemical components as mineral molecules, small amounts of MnO and NiO are to be united with FeO, and of BaO and SrO with CaO; of Cr_2O_3 with Fe_2O_3, unless these unusual components occur in sufficient amounts to make their calculation as special mineral molecules desirable. These amounts are indicated in connection with examples of calculation given later.

3. Establish the fixed molecules by allotting:

a) to Cr_2O_3, if present in notable amount, FeO to satisfy the ratio Cr_2O_3 : FeO : : 1 : 1 for chromite;

b) to TiO_2 enough FeO to satisfy the ratio TiO_2 : FeO : : 1 : 1 for ilmenite. If there is excess of TiO_2, allot to it equal CaO for titanite or perofskite according to available silica, to be determined later. If there is still an excess of TiO_2 it is to be calculated as rutile;

c) to P_2O_5 allot enough CaO to satisfy the ratio P_2O_5 : CaO : : 1 : 3.33 for apatite. Allot F to satisfy $CaO = 0.33P_2O_5$;

d) to F not used in apatite allot CaO to form fluorite, CaO : F : : 1 : 2;

e) to Cl allot Na_2O in the ratio Cl_2 : $Na_2(O)$: : 1 : 1 for sodalite;

f) to SO_3 allot Na_2O in proportion SO_3 : Na_2O : : 1 : 1 for noselite;

g) to S allot FeO in proportion S : Fe(O) : : 2 : 1 for pyrite;

h) to CO_2 in undecomposed rocks allot CaO in the proportion 1 : 1 for calcite. CO_2 may occur in primary calcite and cancrinite. If these minerals are secondary, the CO_2 is to be neglected, since it is understood that analyses of decomposed rocks are not available for purposes of classification.

Having adjusted the minor, inflexible, molecules, there remain the more important but variable silicate molecules, which form the great part of the standard mineral composition, or *norm*, of most rocks.

4. To Al_2O_3 are allotted all the K_2O and Na_2O, not already disposed of, in the proportion of Al_2O_3 : $K_2O + Na_2O$: : 1 : 1 for alkali feldspathic and feldspathoid (lenad) molecules.

5. With excess of Al_2O_3, ($Al_2O_3 > K_2O + Na_2O$):

a) to extra Al_2O_3 allot CaO in proportion of Al_2O_3 : CaO :: 1 : 1 for anorthite molecules.

b) If there is further excess of Al_2O_3 it is to be considered as corundum, Al_2O_3.

It it is not advisable to calculate muscovite with excess of Al_2O_3 instead of corundum, since it requires a readjustment of orthoclase molecules, and muscovite may not occur in the rock, the extra Al_2O_3 entering alferric minerals. Its calculation is considered subsequently.

6. With insufficient Al_2O_3, ($Al_2O_3 < K_2O + Na_2O$):

a) Extra Na_2O is allotted to Fe_2O_3 in proportion Fe_2O_3 : Na_2O :: 1 : 1 for acmite molecules.

b) If there is still extra Na_2O it is set aside for a metasilicate molecule (Na_2SiO_3).

c) When there is an excess of K_2O over Al_2O_3 it is treated in the same manner. It is an extremely rare occurrence.

7. In working with reliable analyses in which Fe_2O_3 and FeO have been correctly determined :

a) To Fe_2O_3 is allotted excess of Na_2O under conditions 6, *a*).

b) To remaining Fe_2O_3 is allotted available FeO in equal proportions for magnetite.

c) If there is any excess of Fe_2O_3 it is calculated as hematite.

Analyses in which all the iron has been determined in one form of oxidation, when it occurs in two, are of little value when considerable iron is present. When the amount of iron is very small the analyses may still be used as a means of classifying the rock. For this purpose all the iron, if given as ferric oxide, is to be calculated as FeO, except that necessary to be allotted to Na_2O for acmite, and then used as below.

8. *a*) Extra CaO after the foregoing assignments is allotted to (Mg, Fe)O in proportion CaO : (Mg, Fe)O :: 1 : 1 for diopside molecules.

In all molecules where (Mg, Fe)O is present, MgO and FeO are to be used in the same proportions in which they are found after FeO has been allotted to the molecules previously mentioned. That is, they are to be introduced into diopside, hypersthene and olivine with the same ratio between them.

b) If there is still an excess of CaO it is to be set aside for calcium metasilicate ($CaSiO_3$) or subsilicate ($4CaO. 3 SiO_2$), equivalent to wollastonite or akermanite. Such extra CaO will in most cases actually enter garnet, an alferric mineral.

9. With insufficient CaO, ($CaO < (Mg, Fe)O$):

a) Extra (Mg, Fe)O is to be set aside for metasilicate or orthosilicate, hypersthene or olivine, according to the amount of SiO_2 present.

The allotment of SiO_2 to form silicates begins with the bases which occur with silica in but one proportion, and is carried on as follows:

10. To ZrO_2 allot SiO_2 in proportion of 1 : 1 for zircon.

11. To CaO and Al_2O_3 in anorthite is allotted equal SiO_2 to form $CaO.Al_2O_3.2SiO_2$.

12. To CaO and (Mg, Fe)O in diopside is allotted equal SiO_2 to form $CaO.(Mg, Fe)O.2SiO_2$.

13. To Na_2O and Fe_2O_3 in acmite is allotted SiO_2 to form $Na_2O. Fe_2O_3.4SiO_2$.

14. To Na_2O (or K_2O) set aside for metasilicate molecules allot SiO_2 to form $Na_2O.SiO_2$ or $K_2O.SiO_2$.

15. To Na_2O and Al_2O_3 in sufficient amount to form with NaCl sodalite, or with Na_2SO_4 noselite, is allotted SiO_2 to satisfy the formulas : $3 (Na_2O.Al_2O_3\ 2SiO_2).2NaCl$, sodalite, $2(Na_2O.Al_2O_3.2SiO_2).Na_2SO_4$ noselite.

The allotment of silica to bases which may form two or more silicates, ortho-, meta- or polysilicate, is controlled in part by the amount of available silica, in part by the affinities of the bases for silica as explained below, in accordance with certain commonly observed facts, as follows:

a) Quartz does not occur with nephelite and leucite, that is, the feldspathic molecules will be polysilicates, orthoclase and albite, if there is sufficient available silica.

b) Of the feldspathoids (lenads), the metasilicates—leucite and analcite—are rarer than the orthosilicates, nephelite and the sodalites. Analcite is so rare as a primary mineral that it may be omitted from the discussion, and may be regarded as composed of albite and nephelite + 2 water. Nephelite is more frequently associated with orthoclase than leucite with albite, from which it appears that potassic feldspathic molecules become polysilicate when sodic ones form orthosilicate. If there is not enough available silica to form orthoclase, leucite forms.

c) The method is also based on the infrequent occurrence of orthorhombic pyroxene with the feldspathoids, and the frequent occurrence of olivine with these minerals. From which may be deduced the rule that the development of metasilicate or orthosilicate of (Mg, Fe)O is controlled in most cases by the available silica after satisfying the feldspathic molecules.

d) Finally, the occurrence of melilite (akermanite) in rocks free from the polysilicate feldspars and the metasilicate, hypersthene, indicates that this subsilicate mineral is produced because of insufficient silica to form the lowest normal silicates commonly developed in igneous rocks.

The order of affinity of the common rock-forming oxides for silica, which is well established by the foregoing and other facts, as well as by such investigations as those of Lagorio[1] and Morozewicz,[2] is as follows, beginning with that which has most affinity, K_2O, Na_2O, CaO, MgO, FeO. The oxides Al_2O_3 and Fe_2O_3 to some extent are analogous to SiO_2 and play in certain respects the rôle of acidic oxides.

The validity of this order is illustrated and confirmed by the following facts: K_2O and Na_2O alone form polysilicates (orthoclase and albite) with the ratios $(K, Na)_2O : SiO_2 :: 1 : 6$. They also form the metasilicates (leucite, analcite and acmite) with the ratio $(K, Na)_2O : SiO_2 :: 1 : 4$. Na_2O also forms the orthosilicate nephelite, as well as the minerals of the sodalite group, with the ratio $Na_2O : SiO_2 :: 1 : 2$. The corresponding potash compound, kaliophilite, is rare and not a rock-making mineral, though K_2O enters into the composition of nephelite to some extent. If potash and soda are present and there is insufficient silica to form polysilicates of both, then as a general rule, K_2O takes all the silica it can get to form orthoclase, or orthoclase and leucite, the soda taking the rest to form nephelite, together with albite in some cases. The occurrence of K_2O in the micas appears at first thought to be an exception to this rule, but further consideration shows that in the muscovite molecule, $(H,K)_2O . Al_2O_3, 2SiO_2$, when $H = 2K$, the SiO_2 is six times K_2O, as in orthoclase; and when $H = K$, the SiO_2 is four times K_2O, as in leucite.

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[1] TSCHENMAK'S *Min. Petr. Mitth.*, Vol. VIII, pp. 421 ff., 1887.

[2] *Ibid.*, Vol. XVIII, pp. 221 ff., 1899.

CaO forms the orthosilicate anorthite with the ratio $CaO : SiO_2 :: 1 : 2$, and controls an amount of SiO_2 equal to itself in the wollastonite molecule. In akermanite the $CaO : SiO_2 :: 4 : 3$.

MgO and FeO can, at most, control only their own amounts of silica, in the hypersthene molecule, and also form the orthosilicate olivine, with the ratio $(Fe, Mg)O : SiO_2 :: 2 : 1$. Finally, FeO crystallizes out in non-siliceous and non-aluminous minerals, magnetite and ilmenite.

It is noteworthy that the order of affinity of these oxides for alumina is the same in relative order as that for silica. So K_2O forms muscovite with an excess of alumina over potash, the analagous paragonite being rare and only found in metamorphic rocks, Na_2O being slightly in excess of Al_2O_3 in the sodalites, CaO largely so (3 : 1) in garnet, and MgO and FeO having little affinity for it.

MgO and FeO can, it is true, form the non-siliceous, aluminous mineral, spinel, $RO. R_2O_3$.

In the calculation of the standard mineral composition the allotment of silica to the alternative molecules is, therefore, as follows:

16. To CaO set aside for wollastonite or akermanite is allotted tentatively SiO_2 to form wollastonite $(CaO . SiO_2)$.

17. To extra $(Mg,Fe)O$ is allotted SiO_2 to form orthosilicate, olivine $(2(Mg,Fe)O . SiO_2)$.

18. To Al_2O_3 and $K_2O + Na_2O$ is allotted SiO_2 to make polysilicate, orthoclase, albite $(K, Na)_2O.Al_2O_3.6\,SiO_2$.

a) If there is excess of SiO_2 it is added to the orthosilicate of (Mg, Fe)O to raise it to the metasilicate $(Mg,Fe)O.SiO_2$. If SiO_2 is insufficient to convert all the olivine into hypersthene it is distributed according to the following equations:

$$x + y = \text{molecules of } (Mg,Fe)O.$$
$$x + \frac{y}{2} = \text{available } SiO_2.$$

where x = hypersthene, y = olivine molecules.

b) Further excess of SiO_2 is to be allotted to TiO_2 and CaO to form titanite. These constituents remain as perofskite when there is no excess of SiO_2.

c) Further excess of SiO_2 is reckoned as quartz.

19. If there is insufficient SiO_2 to form polysilicate feldspar out of all the K_2O and Na_2O with Al_2O_3:

a) To $K_2O.Al_2O_3$ is allotted tentatively enough SiO_2 to form polysilicate, orthoclase $(K_2O.Al_2O_3.6SiO_2)$ and the remaining SiO_2 is distributed between albite and nephelite molecules by means of the equations:

$$x + y = \text{molecules of } Na_2O.$$
$$6x + 2y = \text{available } SiO_2.$$

where x = albite, and y = nephelite molecules.

b) If the available SiO_2 in case 15, *a*) is insufficient to form nephelite with the Na_2O, then enough SiO_2 is first allotted to the Na_2O to form nephelite and the remaining SiO_2 is distributed between orthoclase and leucite molecules by means of the equations:

$$x + y = \text{molecules of } K_2O.$$
$$6x + 4y = \text{available } SiO_2.$$

where x = orthoclase, and y = leucite molecules.

20. If there is insufficient SiO_2 to form leucite and nephelite with olivine it is necessary to reduce a sufficient number of molecules to form the subsilicate akermanite, $4CaO.3SiO_2$.

a) In case there is no wollastonite this is done after distributing SiO_2 tentatively to form leucite, nephelite and olivine and noting the deficit of SiO_2 by means of the equation:

$$y = \frac{1}{3} \text{ of the deficit of } SiO_2.$$

$$y = \text{molecules of akermanite. } (4CaO.3SiO_2).$$

CaO is to be taken from diopside, and the MgO and FeO so liberated are to be calculated as olivine.

b) In case an excess of CaO has been set aside for wollastonite this is first converted to akermanite by means of the equations: $y =$ the deficit of SiO_2.

$$y = \text{molecules of akermanite } (4CaO.3SiO_2).$$

c) If there are not sufficient molecules of wollastonite to satisfy the deficit of silica, recalculate the molecules of diopside and wollastonite so as to make olivine, diopside and akermanite by means of the formulæ.

$$2x + 3y + \frac{z}{2} = \text{available } SiO_2.$$

$$x + 4y = \text{molecules of } CaO.$$

$$x + z = \text{molecules of } MgO + FeO.$$

Where $x =$ molecules of new diopside, $y =$ molecules of akermanite ($4CaO.3SiO_2$), and $z =$ molecules of olivine.

21. If there is still not enough SiO_2, all the CaO of the diopside and wollastonite must be calculated as akermanite, the (Mg, Fe)O being reckoned as olivine and the K_2O distributed between leucite and kaliophilite by the equations:

$$x + y = \text{molecules of } K_2O.$$

$$4x + 2y = \text{available } SiO_2.$$

where x is K_2O in leucite and $y = K_2O$ in kaliophilite.

22 In case there is insufficient SiO_2 and an excess of Al_2O_3 and (Mg,Fe)O, which might form aluminous spinel, an alferric mineral, the excess of Al_2O_3 is to be calculated as corundum, and the uncombined (Mg,Fe)O is to be estimated as femic minerals, being placed with the nonsilicate, mitic, group, magnetite, ilmenite, etc.

It will be noted that as a result of the methods given above the following minerals are not found together in the *norm*, standard mineral composition, of igneous rocks; in other words, that the calculation of the former of each pair precludes that of the latter, and conversely.

With quartz there will be no nephelite, leucite or olivine.
With hypersthene there will be no nephelite or leucite.
With corundum there will be no diopside or acmite.
With anorthite there will be no acmite.
With wollastonite there will be no hypersthene or olivine.
With leucite there will be no albite.

Percentage weights of minerals.—Having estimated the relative number of molecules of the various mineral components, their relative masses may be obtained by multiplying each by the molecular weight. This is readily accomplished by means of tables, both for finding the molecular proportions corresponding to percentages of the chemical components given in analyses, such as those lately published by J. F. Kemp[1] and others, for finding the percentage weights of the minerals with constant composition when their molecular proportions have been calculated. The weights of minerals like olivine and pyroxene in which the component (Mg, Fe) O is variable must be calculated from the proportions of MgO and FeO present in the rock after deduction of FeO allotted to magnetite and ilmenite, the same ratio between these oxides being used for each kind of molecule containing both of them. The weights of diopside, hypersthene and olivine, in which MgO and FeO occur in varying amounts, may be computed from the sums of the simple molecules $CaSiO_3$, $MgSiO_3$, $FeSiO_3$, and Mg_2SiO_4, Fe_2SiO_4.

Tables for finding the molecular proportions of the constituent oxides, and those for the percentage weights of the standard minerals will be found in the reprint of this paper, already alluded to.

EXAMPLES OF CALCULATIONS.

It will be useful to give some examples illustrative of the method of calculation and of the various possibilities, selected from several thousand calculated by us. To simplify them, the molecular weights of the minerals which have fixed molecules, as orthoclase, anorthite, magnetite, etc., are multiplied by the number of molecules of the unit oxide in each case to arrive at the percentage weight.

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[1] KEMP, J. F., "The Recalculation of the Chemical Analyses of Rocks," *School of Mines Quarterly*, Vol. XXII, pp. 75–88.

For general purposes very small amounts of the component oxides may be neglected. But for close work it is necessary to take into account even small percentages of P_2O_5, TiO_2, SO_3, etc., that is, where any one of them amounts to two units in the scale of molecular proportions; when $P_2O_5 = 0.28$, $TiO_2 = 0.16$, $SO_3 = 0.16$, $CO_2 = 0.08$, $Cl = 0.07$, $F = 0.04$ of a per cent.

The introduction of these into the calculation is important in proportion as the amounts of the bases with which they combine are small in the rock.

A check on the results is furnished by the agreement of the sum of the calculated mineral components and the components not included in the calculation with the sum total of the analysis. This check cannot be absolutely exact because of errors in the determination of the last decimal figure in the calculation of each component throughout the process.

The rocks chosen to illustrate the method represent several cases. That of the toscanose (granodiorite), Table I, is the simplest case. Al_2O_3 and SiO_2, being in excess, yield normative corundum and quartz; the femic silicate being hypersthene.

The hessose (amphibole-gabbro), Table II, illustrates the method of adjusting SiO_2 between hypersthene and olivine.

The nordmarkose (litchfieldite), Table III, illustrates the method of distributing SiO_2 between albite and nephelite after reckoning the femic silicate as olivine. All the Na_2O is first allotted to Al_2O_3, and SiO_2 is allotted to orthoclase, anorthite, and olivine; the remainder, 0.680 mol., is distributed according to the formulæ.

In the case of the laurdalose (laurdalite), Table IV, insufficient Al_2O_3 necessitates the formation of acmite molecules. After allotting SiO_2 to orthoclase, acmite, diopside, and olivine, the remainder, 0.522 mol., is distributed between albite and nephelite.

The vesuvose-albanose (leucitite), Table V, illustrates the case in which akermanite (melilite) is required to satisfy the calculation. After allotting SiO_2 to leucite, nephelite, anorthite, diopside, and olivine, there is a deficit of 0.069 mol. SiO_2. This is adjusted by the introduction of akermanite according to the formula, and the recalculation of diopside and olivine. It also illustrates the case of an intermediate rock, between Classes I and II.

TABLE I.

TOSCANOSE (GRANODIORITE) EL CAPITAN, YOSEMITE VALLEY, CAL.

Bull. 168, U. S. Geol. Surv., p. 208.

	Per cent.	Mol.	Ilm.	Mag.	Orth.	Alb.	An.	Cor.	Hyp.	Quartz.
SiO_2 ...	71.08	1.185	....	....	258	342	94	....	27	464
Al_2O_3 ..	15.90	.156	....	....	43	57	47	9	....	....
Fe_2O_3 .	.62	.004	....	4	....	....	....	....	....	....
FeO ...	1.31	.018	3	4	....	....	....	....	11	....
MgO...	.54	.014	....	....	....	....	....	....	14	....
CaO ...	2.60	.047	....	....	....	....	47	....	....	....
Na_2O ..	3.54	.057	....	....	....	57	....	....	....	....
K_2O ...	4.08	.043	....	....	43	....	....	....	....	....
H_2O+	.30	....	....	....	....	....	....	....	....	....
H_2O-.	none	....	....	....	....	....	....	....	....	....
CO_2 ...	tr	....	....	....	....	....	....	....	....	....
TiO_2...	.22	.003	3	....	....	....	....	....	....	....
P_2O_5 ..	.10	.000	....	....	....	....	....	....	....	....
SO_3 ...	none	....	....	....	....	....	....	....	....	....
Cl	.02	.000	....	....	....	....	....	....	....	....
MnO...	.15	.002	....	....	....	....	....	....	2	...
BaO ...	.04	.000	....	....	....	....	....	....	....	....
SrO....	.02	.000	....	....	....	....	....	....	....	....
ZrO_2...	.08	.000	....	....	....	....	....	....	....	....
	100.60									

FORMULA.	MOL. WT.		NORM.				
SiO_2	464 × 60	= quartz	= 27.84	Q	27.84	Sal	95.61
$K_2O.Al_2O_3.6SiO_2$	43 × 556	= orthoclase	= 23.91	F	66.85		
$Na_2O.Al_2O_3.6SiO_2$	57 × 524	= albite	= 29.87				
$CaO.Al_2O_32.SiO_2$	47 × 278	= anorthite	= 13.07				
Al_2O_3	9 × 102	= corundum	= .92	C	.92		
$MgO.SiO_2$	14 × 100	= hypersthene	= 3.11	P	3.11	Fem	4.49
$(Fe, Mn)O.SiO_2$	13 × 132						
$FeO.Fe_2O_3$	4 × 232	= magnetite	= .93	M	1.38		
$FeO.TiO_2$	3 × 152	= ilmenite	= .45				
			100.10				

CLASS I.

$$\frac{\text{Sal}}{\text{Fem}} = \frac{95.6}{4.5} > \frac{7}{1}$$

Persalane.

ORDER 4.

$$\frac{F}{Q} = \frac{66.8}{27.8} > \frac{5}{3} < \frac{7}{1}$$

Britannare.

RANG 2.

$$\frac{K_2O' + Na_2O'}{CaO'} = \frac{100}{47} > \frac{5}{3} < \frac{7}{1}$$

Toscanase.

SUBRANG 3.

$$\frac{K_2O'}{Na_2O'} = \frac{43}{57} < \frac{5}{3} > \frac{3}{5}$$

Toscanose.

TABLE II.

HESSOSE (AMPHIBOLE GABBRO) BEAVER CREEK, BIG TREES QUADRANGLE, CAL.

A. J. S., Vol. VIII (1899), p. 297; *Bull.*, *168*, U. S. G. S., p. 206.

	Per Cent.	Mol.	Apat.	Ilm.	Mag.	Orth.	Alb.	An.	Diop.	Rem'der.	Hyp.	Oliv.
SiO_2	47.27	.788	..	..	..	12	264	306	118	88	37	51
Al_2O_3 ...	20.82	.204	..	..	..	2	44	158	..	..	..	..
Fe_2O_3 ...	1.85	.011	..	..	11	..	..	..	..	..	..	..
FeO	4.26	.059	..	11	11	..	..	..	59	139	37	102
MgO	6.44	.161	..	..	..	..	..	..				
CaO	13.02	.232	15	..	..	..	..	158	59	..	..	..
Na_2O....	2.75	.044	..	..	..	..	44	..	..	..	..	..
K_2O	.22	.002	..	..	..	2	..	..	..	..	..	..
H_2O+ ..	1.27	....	..	..	..	..	..	..	..	..	..	..
H_2O- ..	.08	....	..	..	..	..	..	..	..	..	..	..
TiO_2	.92	.011	..	11	..	..	..	..	..	..	..	..
P_2O_5	.74	.005	5	..	..	..	..	..	..	..	..	..
Cl.......	tr	....	..	..	..	..	..	..	..	..	..	..
Cr_2O_3 ...	tr	....	..	..	..	..	..	..	..	..	..	..
MnO	tr	....	..	..	..	..	..	..	..	..	..	..
SrO	tr	....	..	..	..	..	..	..	..	..	..	..
V_2O_3....	.02	....	..	..	..	..	..	..	..	..	..	..
FeS_2	.20	...	..	..	..	..	..	..	..	..	..	..
	99.86											

$$x + \frac{y}{2} = 88\ SiO_2$$

$$x + y = 139\ (Mg, Fe)\ O$$

$$y = 102$$

$$x = 37$$

FORMULA.	MOL. WT.		NORM.				
$K_2O.Al_2O_3.6SiO_2$	2 × 556	= orthoclase =	1.11	F	68.09	Sal	68.09
$Na_2O.Al_2O_3.6SiO_2$	44 × 524	= albite =	23.06				
$CaO.Al_2O_2.2SiO_2$	158 × 278	= anorthite =	43.92				
$CaO.SiO_2$	59 × 116	= diopside =	13.10	P + O	24.77	Fem	30.74
$MgO.SiO_2$	48 × 100						
$FeO.SiO_2$	11 × 32						
$MgO\ SiO_2$	30 × 100	= hypersthene =	3.92				
$FeO.SiO_2$	7 × 132						
$2MgO.SiO_2$	83 × 70	= olivine =	7.75				
$2FeO.SiO_2$	19 × 102						
$FeO.Fe_2O_3$	11 × 232	= magnetite =	2.55	M	4.22		
$FeO.TiO_2$	11 × 152	= ilmenite =	1.67				
$3CaO.P_2O_5$	5 × 310	= apatite =	1.55	A	1.75		
FeS_2		pyrite =	.20				
		etc. =	1.37				
			100.20				

CLASS II.

$$\frac{Sal}{Fem} = \frac{68.09}{30.74} < \frac{7}{1} > \frac{5}{3}$$

Dosalane.

ORDER 5.

$$\frac{F}{Q} = \frac{68.09}{0} > \frac{7}{1}$$

Germanare.

RANG 4.

$$\frac{K_2O' + Na_2O'}{CaO'} = \frac{46}{158} < \frac{3}{5} > \frac{1}{7}$$

Hessose.

SUBRANG 3.

$$\frac{K_2O'}{Na_2O'} = \frac{2}{44} < \frac{1}{7}$$

Hessose.

TABLE III.

NORDMARKOSE (LITCHFIELDITE), LITCHFIELD, ME.

Bull. 168, U. S. Geol. Surv., p. 21.

	Per cent.	Mol.	Orth.	Alb.	Nep.	An.	Cor.	Mag.	Oliv.
				612	68				
SiO_2	60.39	1.006	300	680		10	..	..	16
				102	34				
Al_2O_3	22.57	.221	50	136		5	30	..	..
Fe_2O_3	.42	.003	...	...	..	..	..	3	..
FeO	2.26	.030	...	...	..	..	..	3	27
MgO......	.13	.003	...	...	..	..	..	..	3
CaO.......	.32	.005	...	...	..	5	..	..	..
				102	34				
Na_2O	8.44	.136	...	136		..	..	..	..
K_2O	4.77	.050	50	...	..	..	..	..	..
H_2O+ H_2O- ..	.57	....	...	...	..	..	..	..	..
MnO......	.08	.001	...	...	..	..	..	..	1
	99.95								

$$1.006-(0.300+0.010+0.016)=0.680$$
$$6x+2y=680\ (SiO_2)$$
$$x+y=136\ (Na_2O)$$
$$x=102$$
$$y=34$$

In the rock the extra Al_2O_3 enters mica, combining with the olivine and magnetite molecules and because of low magnesia making lepidomelane.

FORMULA.	MOL. WT.	NORM.				
$K_2O.Al_2O_3.6SiO_2$ - - -	50 × 556	= orthoclase =	27.80	F	Sal	95.35
$Na_2O.Al_2O_3.6SiO_2$ - -	102 × 524	= albite =	53.45			
$CaO.Al_2O_3.2SiO_2$ - - -	5 × 278	= anorthite =	1.39			
$Na_2O.Al_2O_3.2SiO_2$ - -	34 × 284	= nephelite =	9.66	L		
Al_2O_3. - - - - -	30 × 102	= corundum =	3.06	C		
$FeO.Fe_2O_3$ - - - -	3 × 232	= magnetite =	.70	M	Fem	3.81
$2MgO.SiO_2$ - - - - -	3 × 70	= olivine =	3.11	O		
$2FeO.SiO_2$ - - - -	28 × 102					
		H_2O =	.57			
			99.73			

CLASS I.

$$\frac{Sal}{Fem}=\frac{95.35}{3.81}>\frac{7}{1}$$

Persalane.

ORDER 5.

$$\frac{F}{L}=\frac{82.64}{9.66}>\frac{7}{1}$$

Canadare.

RANG 1.

$$\frac{K_2O'+Na_2O'}{CaO'}=\frac{186}{3}>\frac{7}{1}$$

Nordmarkase.

SUBRANG 4.

$$\frac{K_2O'}{Na_2O'}=\frac{50}{136}<\frac{3}{5}>\frac{1}{7}$$

Nordmarkose.

TABLE IV.

LAURDALOSE (LAUDALITE), WEST OF POLLEN, LAUGENDAL, NORWAY.

BRÖGGER, W. C., *Die Eruptivgesteine des Christiania Gebietes*, Vol. III, p. 19.

	Per cent.	Mol.	Ap.	Ilm.	Orth.	Alb.	Nep.	Acm.	Mag.	Diop.	Oliv.
						366	156				
SiO_2	56.35	.939	..	..	336	522		16	..	62	3
						61	78				
Al_2O_3 ...	19.85	.195	..	..	56	139		..	..	..	..
Fe_2O_3 ...	1.91	.012	..	..	...	...	...	4	8	..	..
FeO	2.03	.028	..	12	...	...	...	..	8	7	1
MgO	1.17	.029	..	..	...	...	...	..	..	24	5
CaO	2.60	.046	15	..	...	...	...	..	..	31	..
						61	78				
Na_2O....	8.89	.143	..	..	...	139		4	..	..	..
K_2O.....	5.31	.056	..	..	56	...	...	..	..	..	..
H_2O	.70	....	..	..	...	...	...	..	..	..	..
TiO_2	1.00	.012	..	12	...	...	...	..	..	..	..
P_2O_5	.67	.005	5	..	...	...	...	..	..	..	..
	100.68										

$$6x + 2y = 522\ (SiO_2)$$
$$x + y = 139\ (Na_2O)$$
$$x = 61$$
$$y = 78$$

FORMULA.	MOL. WT.		NORM.				
$K_2O.Al_2O_3.6SiO_2$	56 × 556	= orthoclase =	31.14	F	63.10	Sal	85.25
$Na_2O.Al_2O_3.6SiO_2$	61 × 524	= albite =	31.96				
$Na_2O.Al_2O_3.2SiO_2$	78 × 284	= nephelite =	22.15	L	22.15		
$Na_2O.Fe_2O_3.4SiO_2$	4 × 462	= acmite =	1.85	P	8.77	Fem	14.45
$CaO.SiO_2$	31 × 116	= diopside =	6.92				
$MgO.SiO_2$	24 × 100						
$FeO.SiO_2$	7 × 132						
$2MgO.SiO_2$	5 × 70	= olivine =	.46	O	.46		
$2FeO.SiO_2$	1 × 102						
$FeO.Fe_2O_3$	8 × 232	= magnetite =	1.86	M	3.68		
$FeO.TiO_2$	12 × 152	= ilmenite =	1.82				
$3CaO.P_2O_5$	5 × 310	= apatite =	1.55	A	1.55		
		H_2O =	.70				
			100.41				

CLASS II.

$$\frac{\text{Sal}}{\text{Fem}} = \frac{85.25}{14.45} < \frac{7}{1} > \frac{5}{3}$$

Dosalane.

ORDER 6.

$$\frac{F}{L} = \frac{63.10}{22.15} < \frac{7}{1} > \frac{5}{3}$$

Norgare.

RANG 1.

$$\frac{K_2O' + Na_2O'}{CaO'} = \frac{195}{0} > \frac{7}{1}$$

Laurdalase.

SUBRANG 4.

$$\frac{K_2O'}{Na_2O'} = \frac{56}{139} < \frac{3}{5} > \frac{1}{7}$$

Laurdalose.

TABLE V.

VESUVOSE-ALBANOSE (LEUCITITE). CAPO DI BOVE, ITALY.

A. J. S., Vol. IX (1900), p. 56.

	Per cent.	Mol.	Ilm.	Leuc.	Nep.	An.	Mag.	Tentative.		Deficit.	Final.		
								Diop.	Oliv.		Ak.[1]	Diop.	Oliv.
SiO_2 .	45.99	.767	....	376	70	78	....	298	14	69	69	114	60
Al_2O_3	17.12	.168	....	94	35	39	....	....	....	....	....	....	....
Fe_2O_3	4.17	.026	....	....	....	....	26	....	....	....	....	....	....
FeO . .	5.38	.075	5	....	....	....	26	37	7	....	....	14	30
MgO. .	5.30	.133	....	....	....	....	....	112	21	....	....	43	90
CaO . .	10.47	.187	....	....	....	39	....	148	....	....	92	56	....
Na_2O .	2.18	.035	....	....	35	....	....	....	....	....	....	....	....
K_2O . .	8.97	.094	....	94	....	....	....	....	....	....	....	....	....
H_2O .	.45	....	....	....	....	....	....	....	....	....	....	....	....
TiO_2 .	.37	.005	5	....	....	....	....	....	....	....	....	....	....
MnO. .	tr	....	....	....	....	....	....	....	....	....	....	....	....
BaO. .	.25	.001	....	....	....	....	....	1	....	....	....	1	....
SrO . .	none	....	....	....	....	....	....	....	....	....	....	....	....
		....	....	....	....	....	....	....	....	....	....	....	....
	100.65	....	....	....	....	....	....	....	....	....	....	....	....

[1] Mol. of akermanite $= y = \frac{69}{3} = 23$.

FORMULA.	MOL. WT.		NORM.		
$K_2O.Al_2O_3.4SiO_2$	94 × 436	= leucite =	40.98	L = 50.92	Sal 61.76
$Na_2O.Al_2O_32SiO_2$	35 × 284	= nephelite =	9.94		
$CaO.Al_2O_3.2SiO_2$	39 × 278	= anorthite =	10.84	F = 10.84	
$CaO.SiO_2$	57 × 116	= diopside =	12.76	P = 12.76	Fem 38.20
$MgO.SiO_2$	43 × 100				
$FeO.SiO_2$	14 × 132				
$2MgO.SiO_2$	90 × 70	= olivine =	9.36	O = 18.65	
$2FeO.SiO_2$	30 × 102				
$4CaO.3SiO_2$	23 × 404	= akermanite =	9.29		
$FeO.Fe_2O_3$	26 × 232	= magnetite =	6.03	M = 6.79	
$FeO.TiO_2$	5 × 152	= ilmenite =	.76		
		H_2O	.45		
			100.41		

CLASS III.

$$\frac{Sal}{Fem} = \frac{61.76}{38.20} < \frac{5}{3} > \frac{3}{5}$$

Dosalane-salfemane.

ORDER 6.

$$\frac{F}{L} = \frac{10.84}{50.92} < \frac{3}{5} > \frac{1}{7}$$

Campanare-bohemare.

RANG 2.

$$\frac{K_2O' + Na_2O'}{CaO'} = \frac{129}{39} < \frac{7}{1} > \frac{5}{3}$$

Vesuvase-albanase.

SUBRANG 2.

$$\frac{K_2O'}{Na_2O'} = \frac{94}{35} < \frac{7}{1} > \frac{5}{3}$$

Vesuvose albanose.

The janeirose (pseudo-leucite-sodalite-tinguaite), Table VI, illustrates the method of calculating leucite and orthoclase, as well as sodalite and noselite. After allotting SiO_2 to nephelite, acmite, diopside, and olivine, the remainder of SiO_2 is 0.546 mol.

TABLE VI.

JANEIROSE (PSEUDO-LEUCITE-SODALITE-TINGUAITE) BEAVER CREEK, BEARPAW MOUNTAINS, MONT.

Bull. 168, U. S. Geol. Surv., p. 136.

	Per cent.	Mol.	Ilm.	Fluor.	NaCl.	Na_2SO_4.	Calcite.	Orth.	Leuc.	Nep.[1]	Acm.	Diop.	Oliv.
								390	156				
SiO_2 .	51.93	.866	..	..	..	..	..	546		192	88	38	2
								65	39				
Al_2O_3	20.29	.200	..	..	..	..	..	104		96	..	..	..
Fe_2O_3	3.59	.022	..	..	..	..	..	..	..	..	22	..	..
FeO ..	1.20	.018	2	..	..	..	..	..	..	..	..	14	2
MgO ..	.22	.006	..	..	..	..	..	..	..	..	..	5	1
CaO ..	1.65	.030	..	7	..	..	6	..	..	..	..	17	..
Na_2O .	8.49	.137	..	..	10	9	..	..	..	96	22	..	..
								65	39				..
													..
K_2O ..	9.81	.104	..	..	..	..	..	104		..	..	..	..
H_2O+	.10	....	..	..	..	..	..	..	..	..	..	..	..
H_2O-	.99	....	..	..	..	..	..	..	..	..	..	..	..
TiO_2 ..	.20	.002	2	..	..	..	..	..	..	...	..	..	..
P_2O_5 .	.06	.000	..	..	..	..	..	..	..	..	..	..	..
SrO ..	.07	.001	..	..	..	..	..	..	..	..	..	1	..
BaO ..	.09	.001	..	..	..	..	..	..	..	..	..	1	..
SO_3 ..	.67	.009	..	..	..	9	..	..	..	..	..	..	..
CO_2 ..	.25	.006	..	..	..	..	6	..	..	..	..	..	..
Cl	.70	.020	..	..	20	..	..	..	..	..	..	..	..
F	.27	.014	..	14	..	..	..	..	..	..	..	..	..
		....	..	..	..	..	..	..	..	..	..	..	..
	100.58	....	..	..	..	..	..	..	..	..	..	..	..
	.27	....	..	..	..	..	..	..	..	..	..	..	..
		....	..	..	..	..	..	..	..	..	..	..	..
	100.31	....	..	..	..	..	..	..	..	..	..	..	..

---

[1] For nephelite, sodalite, and noselite.

$$
\begin{aligned}
6x + 4y &= 546\ (SiO_2) \\
x + y &= 104\ (K_2O) \\
x &= 65 \\
y &= 39
\end{aligned}
$$

FORMULA.	MOL. WT.		NORM.			
$K_2O.Al_2O_3.6SiO_2$	65 × 556	= orthoclase =	36.14	F	36.14	
$K_2O.Al_2O_3.4SiO_2$	39 × 436	= leucite=	17.00			Sal. 82.75
$Na_2O.Al_2O_3.2SiO_2$	48 × 284	= nephelite =	13.63	L	46.61	
$3(Na_2O.Al_2O_3.2SiO_2)2(NaCl)$	10 × 969	= sodalite	9.69			
$2(Na_2O.Al_2O_3.2SiO_2)Na_2SO_4$	9 × 699	= noselite	6.29			
$Na_2O.Fe_2O_3.4SiO_2$	22 × 462	acmite	10.16			
$CaO.SiO_2$	17 × 116			P	14.48	
$MgO.SiO_2$	5 × 100	diopside	4.32			
$FeO.SiO_2$	14 × 132					
$2MgO.SiO_2$	1 × 70	olivine	.27	O	.27	Fem. 15.60
$2FeO.SiO_2$	2 × 102					
$FeO.TiO_2$	2 × 152	ilmenite	.30	M	.30	
CaF_2	7 × 78	fluorite	.55	A	.55	
$CaO.CO_2$	6 × 100	calcite	.60			
		H_2O	1.09			
			100.04			

CLASS II.	ORDER 7.	RANG 1.	SUBRANG 3.
$\frac{\text{Sal}}{\text{Fem}} = \frac{82.75}{15.60} < \frac{7}{1} > \frac{5}{3}$	$\frac{\text{F}}{\text{L}} = \frac{36.14}{46.61} < \frac{5}{3} > \frac{3}{5}$	$\frac{K_2O' + Na_2O'}{CaO'} = \frac{219}{0} > \frac{7}{1}$	$\frac{K_2O'}{Na_2O'} = \frac{104}{115} < \frac{5}{3} > \frac{3}{5}$
Dosalane.	*Italare.*	*Lujavrase.*	*Janeirose.*

The calculation of the norm from the mode.— Having described the process by which the norm may be calculated from the chemical analysis of a rock, there remains the discussion of the process by which it may be calculated directly from the actual mineral composition of the rock without having the chemical analysis.

The first requisite in this case is a knowledge of the actual mineral composition of a particular rock, and it is evident that not every rock is sufficiently well crystallized to permit even an approximate estimate of the kinds and quantities of all the minerals present. Consequently there are very many rocks in which the norm cannot be calculated directly from the rock without recourse to a chemical analysis. These are partly glassy rocks, and those that are so fine-grained that the individual mineral components cannot be identified and measured.

But it is possible with some rocks to determine very closely the proportions of the minerals present in them. Such rocks are holocrystalline, and the crystals are sufficiently large to permit their individuality and outline to be recognized. With such rocks the method of determining the quantity of all the mineral components is as follows:

Estimate by accurate measurement the volumetric proportions of all the component minerals. This may be accomplished by measuring with a micrometer the diameters of each crystal in lines across thin sections of a rock, care being taken to measure a distance at least one hundred times the average grain of the rock.[1] The proportions found for the lengths of diameters of the various components will correspond to those of their volumes. Several other methods have been devised which are less accurate and need not be described here.

The volumetric proportions are to be reduced to relative masses by multiplying the volume of each mineral by its specific gravity and reducing the total to one hundred parts.

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[1] ROSIWAL, *Verh. Wien. Geol. Reichs-Anst.*, Vol. XXXII, pp. 143 ff., 1898.

Accurate quantitative determination of the mineral components of rocks by optical methods is difficult with coarse-grained and coarsely porphyritic rocks as well as with extremely fine-grained ones. When the rock contains large crystals a comparatively large area of it must be measured to obtain correct proportions of the component minerals. A few thin sections are not adequate. The measurements must be made megascopically. The same is true when there are large phenocrysts. A sufficiently large area of surface must be measured to furnish a correct estimate of the relative proportions of the several kinds of phenocrysts and the groundmass. Subsequently the groundmass may be studied and measured with a microscope and the two sets of measurements combined.

In very fine-grained rocks, where the kinds of minerals composing them can all be identified, the accuracy of measurements of the diameters of crystals with a microscope is affected by the overlapping of crystals within the section, and it is found by experience that the amount of the colored crystals is overestimated, while that of the colorless ones is underestimated. This is particularly the case where the thickness of crystals is a fraction of the thickness of the rock section, as with microlites and minute inclusions. It will be necessary to determine corrections to be applied in such cases by working on microcrystalline or microlitic rocks whose chemical composition has been determined.

If all of the minerals actually present in a holocrystalline rock are standard minerals, salic or femic, there may still be uncertainty as to the norm, since the proportions of the standard minerals actually developed may not accord with those constituting the norm. In all cases it is necessary to calculate the norm from the actual mineral composition quantitatively determined by estimating the chemical composition of the rock from that of each of its component minerals, and from this analysis deducing the norm as in the first method described.

This involves the determination of the chemical composition of the actual minerals present in the rock. For a certain number this may be based on optical investigation. The composition of minerals with constant or comparatively simple molecules may be taken as that of the ideal molecule, as, for example, in such minerals as quartz, orthoclase, albite, anorthite, leucite, nephelite, apatite, zircon, titanite, etc.

The proportions of the chemical components reckoned as oxides belonging to each of these minerals must be multiplied by the percentage weight of each mineral to furnish the chemical components of the whole rock. Thus 35 per cent. of quartz = 35 per cent. of SiO_2; 10 per cent. of orthoclase = 6.47 per cent. of SiO_2, 1.83 per cent. Al_2O_3, 1.69 per cent. K_2O.

When the mineral has no fixed chemical molecule, as, for example, olivine, in which Mg and Fe are variable, it is necessary to consider the composition most likely to obtain for the mineral in a rock of about the character of the one under investigation, or to observe more specifically the optical properties of the mineral where these are characteristic of the chemical composition.

For the plagioclase feldspars the optical properties have been elaborately investigated and are well known. It is necessary to determine as accurately as possibly by Michel-Lévy[1] methods, aided by Becke's[2] method, the composition of the striated feldspars, noting the variation in zones, and estimating approximately the average composition of the crystals. The ratios of Ab to An must be transposed into ratios between Na_2O and CaO by halving the value of Ab. For the reason that Ab stands for the formula $NaAlSi_3O_8$ and An for the formula $CaAl_2Si_2O_8$. In the first there is only one Na, hence Ab : An : : Na : Ca. When we express the composition of albite by $Na_2O.Al_2O_3.6SiO_2$, we are using 2Ab. And in estimating Na_2O from the albite combined with anorthite in a plagioclase feldspar we obtain one-half as many molecules of Na_2O as we have Ab derived from the familiar symbol of a plagioclase, Ab_nAn_m.

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[1] *Étude sur la détermination des feldspaths* (Paris), 1re fasicule, 1894; 2me fasicule, 1896.

[2] *Sitzungsb. Akad. Wiss. Wien.*, Vol. CII, Part I, pp. 358–76, 1893.

A less precise method may be used, which is sufficiently accurate considering the inaccuracy of the approximation to the average composition of zonally built feldspars, namely, to apply the ratio Ab/An obtained optically directly to the percentage weights of plagioclase. Thus 50 per cent. of plagioclase, whose average composition has been estimated at Ab_3An_2, may be separated into 30 per cent. albite and 20 per cent. anorthite with approximate correctness.

In the case of hornblende, augite, and mica, the color and optical properties are undoubtedly equally characteristic, but they have not received sufficient attention to permit of the same direct application. They are, however, guides to the choice of typical formulas or chemical analyses, which may be used temporarily in place of more exact methods.

For this purpose tables have been arranged giving the chemical analyses of certain rock-making alferric minerals, and also the analyses of the rocks in which these minerals occur. From these it is possible to select cases corresponding more or less closely to those in the rock whose norm is to be determined. For it appears from data already at hand that the chemical composition of each mineral in a rock bears such a relation to the chemical composition of the whole rock, that minerals of the same kind, for example the hornblendes, when they occur in similar rocks have very nearly the same composition. The compositions of the hornblendes and micas in the granodiorite of the Sierra Nevada, California, and of those in the very similar quartz-monzonite of Butte, Montana, are nearly the same.

For minerals with variable composition, then, select from Tables of Analyses the analysis of the mineral corresponding most closely to the one in the rock in question, considering both its optical characters and the general character of the rock in which it occurs, and reduce its several chemical constituents to the proper amount by multiplying by the percentage of the mineral as determined from the rock.

Having reduced each mineral to its chemical constituents the sum of the constituents will represent the chemical composition of the rock. From this the salic and femic minerals may be calculated as in the first instance, and the norm determined.

In many cases it will not be necessary to reduce all of the minerals to their chemical constituents in order to determine the norm. For the minerals may be largely salic or femic as they occur in the rock. This is the case with the feldspars, feldspathoids (lenads), and quartz, with orthorhombic pyroxenes, olivine, diopside, magnetite, etc.

It is chiefly the aluminous ferromagnesian minerals that require reduction. And for first approximations the proportions of salic and femic constituents contained in these minerals are given in Tables XII, XIII, and XIV at the end of this Part.

From these it is seen that in aluminous pyroxenes the proportion of the salic component is often 0.10, and does not exceed 0.23. The femic component is 0.90 in most cases, and rarely 0.77.

For hornblende and closely related amphiboles the salic component is from 0.20 to 0.34, and in the more sodic amphiboles it is about 0.10.

For micas the two components are nearly equal, that is, 0.50 each.

When the amounts of salic and femic components are known the Class of the rock is established. For rocks of the first three Classes the next step is the determination of the relative amounts of quartz, feldspar, and feldspathoid. For persalane rocks this is comparatively simple, since the other minerals are present in small amounts. But as the amount of mica, amphibole, and augite increases it becomes necessary to determine more accurately the nature of the salic component involved in each, in order to adjust the silica before reckoning the proportions of quartz, feldspar, or feldspathoids. In such cases the first method must be followed, or the aluminous ferromagnesian minerals must be resolved into aluminous and non-aluminous portions and the silica adjusted to these portions and to the other salic and femic components, according to the method given for calculating the standard minerals.

The determinations of Rang and Subrang as well as of Grad and Subgrad follow the calculation of the chemical components.

THE CALCULATION OF THE MODE FROM THE CHEMICAL ANALYSIS OF A ROCK.

This is often desired in order to compare the two, and to determine the amount of the chemical composition of some of the component minerals, not otherwise determinable.

But it is evident that the knowledge of the actual minerals present in the rock cannot be learned directly from the chemical analysis, since various mineral combinations may be formed within certain limits. It is therefore necessary to determine the presence of these minerals by a study of the rock, and this involves microscopical investigation in nearly all cases. This has generally meant the simple enumeration of the kinds of minerals present, with the crudest statement of their relative proportions.

In some instances this would furnish data enough for the solution of the problem, but it is clear that such cases must be those in which all the minerals present are salic and femic, without intermediate, alferric, kinds, or those cases in which the alferric minerals are developed to their limit, as for example, hornblende present to the exclusion of diopside, or to the exclusion of hypersthene and olivine; biotite present to the exclusion of hypersthene and olivine, or to the exclusion of potash-feldspathic minerals, or to the exhaustion of available alumina.

Under such circumstances it would be possible to calculate the composition and proportions of the actual minerals. But even in these cases the variable chemical character of amphiboles and micas renders the solution of the problem untrustworthy unless the composition of the particular amphibole or mica be known exactly or approximately.

This involves the separation and analysis of one or both of these minerals, or the reasonable assumption that they have approximately the same composition as other amphiboles and micas which have been analyzed.

Further consideration of the problem will convince one that where augites, amphiboles, and micas occur with femic minerals, such as diopside, hypersthene, and olivine, the problem cannot be solved by simply determining the kinds of minerals present in the rock. The algebraic equations involve too many unknown quantities. In other words, there may be variable amounts of the same minerals developed from chemically similar magmas. It becomes necessary then to determine the relative amounts of several of these minerals, according to the number of them, in order to reduce the number of unknown quantities in the algebraic equations. Then it is possible, with part of the problem solved by microscopical study, to complete it by estimating the remaining factors from the chemical analysis of the rock. That is to say, in most cases the microscopical and chemical methods must supplement one another.

Thus it is possible to calculate the probable composition of a hornblende in a given rock when all the other minerals have comparatively simple, or fixed, molecules, and when the quantity of the hornblende has been determined optically. In another case, if hornblende has been separated from the rock and analyzed, it is possible to calculate the probable composition of a biotite present, when the proportions of these two minerals are known, and the other minerals in the rock have fixed molecules.

The same process may be used to determine the composition of the groundmass, when the character and percentages of the phenocrysts have been determined.

The method of calculation, which is illustrated by the case of the Butte granite given on a subsequent page, may be stated as follows:

Starting with the chemical analysis of the rock, reduce it to molecular proportions by dividing the percentage of each chemical component by its molecular weight.

Deduct from these molecules the molecules belonging to such minerals as have been chemically and quantitatively determined.

The remaining oxide molecules are to be distributed among the minerals with fixed molecules, whose quantity, however, is undetermined, by assigning to each mineral its proper oxide molecules in the proportions in which they occur in the ideal mineral molecule, as, for example; for orthoclase, $1K_2O.1Al_2O_3.6SiO_2$, and further, by indicating the number of molecules of each mineral by an algebraic symbol or letter. Thus, if there are x molecules of orthoclase, there must be assigned to them $xK_2O.xAl_2O_3.6xSiO_2$. The sum of all these assigned oxide molecules must equal the total amount of a particular chemical component in the rock after deducting that belonging to the minerals whose composition and quantity have been determined.

If there are more variable quantities than equations, that is, in general, more kinds of minerals than chemical components, it is necessary to reduce the number of unknown quantities by fixing the relative amounts of several minerals, or by stating their actual amounts.

THE CALCULATION OF ALFERRIC MINERALS.

As pointed out in the discussion of the classification of igneous rocks on a basis of salic and femic minerals, the reasons for omitting the alferric minerals are their variable and complex composition, our inadequate knowledge of the chemical character of the amphiboles and micas, and the inconstancy of their crystallization from magmas of any given chemical composition.

The questions naturally arise, How may these minerals be introduced into the calculation of the mineral composition of rocks from rock analyses ? And what modifications of the norm would follow their introduction ?

These questions, though not important for the classification of rocks according to the system here proposed, are of interest because of their relation to the general problem of chemico-mineralogical classification and the possibilities of its assuming a more elaborate form than that given it by us. The discussion of them emphasizes the relations between the aluminous ferromagnesian minerals and the salic and femic minerals, and makes evident the effect of the crystallization of the alferric minerals in a given magma upon the proportions of the other minerals.

We shall consider the problem of converting portions of salic and femic minerals, already calculated from the analysis of a rock, into alferric minerals. The minerals in question are: aluminous pyroxenes, aluminous amphiboles, micas and garnets. Rarer minerals of this kind will not be considered. As to the chemical composition of these minerals, it is known that the amounts of alumina and ferric oxide in monoclinic pyroxenes, amphiboles, and micas vary considerably in different cases, so that no simple statement can be made regarding the ratios of alumina to other constituents in these minerals. Moreover, there is no fixed relation between the amount of aluminous ferromagnesian minerals actually crystallized in a rock and the chemical composition of its magma. However, a study of the chemical composition of these minerals, so far as they have been analyzed, shows that their composition bears some relation to that of the magma from which they crystallized. In order to present this relationship as clearly as possible, Tables XII, XIII, and XIV have been arranged, as already mentioned, giving the chemical analyses of aluminous pyroxenes, amphiboles, and micas, and those of the rocks from which they were separated. It is evident from these tables that there is need for much thorough chemical investigation of the rock-making pyroxenes, amphiboles, and micas before we shall be in a position to cope successfully with the problem before us. For the present we can explain the method of dealing with the known factors in the problem and indicate that which may be pursued in doubtful cases.

The solution of the problem involves the transfer of alumina from salic to femic molecules, the necessity of introducing it in proportions corresponding to the known composition of these minerals in each case, the consequent readjustment of molecules among the femic minerals, and the disarrangement and readjustment of molecules among the salic minerals.

The process appears at first sight complex, but only involves simple algebra, and when applied to a concrete example is not very intricate. Its value consists in familiarizing the student or investigator with the interdependence of the various mineral molecules in an igneous rock, and with the ranges of variation possible within rocks of the same chemical composition.

The minerals in question being characterized by a variable content of alumina, it is of first importance to note the amount of alumina present in different cases and to consider what transfer of chemical elements from salic to femic molecules would be necessary in order to produce such aluminous ferromagnesian minerals without destroying the stoichiometric proportions in the remaining salic and femic minerals.

In the case of a rock in which the calculation of the standard mineral composition showed the presence of an excess of Al_2O_3 over that required to form salic minerals it is evident that Al_2O_3 may be introduced into the ferromagnesian minerals by transferring it from this extra Al_2O_3.

But in the great majority of rocks there is no excess of Al_2O_3 in the sense here employed, and the production of aluminous ferromagnesian minerals affects the standard feldspathic molecules, so that the transfer of Al_2O_3 necessitates the transfer of those chemical bases united with it in equal proportions, namely, calcium, sodium, and potassium.

Each of these elements may enter into the composition of the minerals to be developed, whose molecules are more complex than those of femic minerals. A study of the analyses of the minerals in question shows that sodium enters into aluminous amphiboles independently of the acmite-riebeckite molecule ($Na_2O \cdot Fe_2O_3 \cdot 4SiO_2$), and that potassium also does, but to so small an extent in most instances that the error of estimating all of the alkali molecules as Na_2O is negligible. Conversely, potassium enters largely into the micas, and the sodium present is so small that the alkali molecules in mica may be calculated as though wholly K_2O without notable error.

Several chemico-mineralogical relations appear to control the amount of alumina, lime, and alkalies that may be transferred from salic to femic minerals to form alferric minerals. And since the transfer of Al_2O_3 involves the CaO, K_2O, and Na_2O to various degrees, it is convenient to compare the amount of Al_2O_3 to be transferred with the principal one of these components taking part in the aluminous ferromagnesian mineral. This component becomes a unit of comparison for the other constituents of the particular mineral. In the pyroxenes and amphiboles CaO is the component next to Al_2O_3 most involved in the change. It becomes the unit of comparison in these minerals. In the micas K_2O plays this rôle.

The molecular relations which must be taken into account are expressed by ratios in the Tables XII, XIII, XIV at the end of this Part, and may be summed up as follows:

Aluminous pyroxenes (*Table XII*).—1. The ratio of Al_2O_3 to CaO ranges from almost nothing to 0.23. From these data the maximum limit is

$$\frac{Al_2O_3}{CaO} = 0.23 .$$

2. The nearly equal proportions between Fe_2O_3 and Na_2O indicate that the soda is present in the acmite molecule.

3. The generally small ratio between Na_2O and CaO. The ratio $\frac{Na_2O}{CaO}$ is less than 0.1 in most cases. Moreover, the presence of a notable amount of acmite molecule is indicated by the optical properties of the pyroxene.

4. The nearly constant ratio between MgO+FeO and CaO, which is approximately

$$\frac{MgO + FeO}{CaO} = 1 .$$

5. The $SiO_2 + TiO_2$ is approximately equal to the number of molecules of $MgO + FeO + CaO + 4Na_2O$, corresponding to pyroxene molecules $(MgFe)O . CaO . 2SiO_2$ and $Na_2O . Fe_2O_3 . 4SiO_2$ and $(Mg, Fe)O. (Al, Fe)_2O_3 \cdot SiO_2$.

Aluminous amphiboles (*Table XIII*).—The relations are less definite. There is a wide range in chemical composition, and it will be necessary to consider special kinds of amphibole in different cases.

a). 1. For *hornblende* occurring in rocks with lime-soda-feldspar the ratio of Na_2O to CaO ranges from 0.08 to 0.21, while for hornblende in one alkali feldspathic rock it is 0.28, and for somewhat similar amphiboles, barkevikite and hastingsite, it reaches 0.35 and 0.43.

2. The ratio of Al_2O_3 to CaO ranges from 0.32 to 0.67 in the first mentioned cases, common hornblende, and from 0.44 to 0.85 in the second.

3. The ratio of MgO + FeO to CaO ranges from 1.73 to 2.72, being nearly 2.2 in most cases. It is not 3, as given in the text-books generally.

4. It is to be noted that in hornblende in the more calcic rocks the ratio of MgO to FeO is 2 or more (from 2 to 4), while in those in the perfelic, alkalic rocks, this ratio is less than 1 (from 0.1 to 0.6). In other words, magnesia dominates ferrous iron in amphiboles of the first kind, while ferrous iron largely preponderates in those of the second kind,

5. The $SiO_2 + TiO_2$ is equal to the MgO + FeO + CaO plus an amount sometimes equal to $4Na_2O$, but not always.

6. The ratio of Fe_2O_3 to CaO is quite variable.

b) For *soda-amphiboles* of various kinds, excepting that occurring in comendite.

1. The ratio of Na_2O to CaO ranges from 1.23 to 4.6. That is, the lime is considerably less than the soda.

2. The ratio of Al_2O_3 to CaO ranges from 0.23 to 1.3.

3. The ratio of MgO + FeO to CaO ranges from 4.6 to 21.6, and the FeO is greatly in excess of MgO.

4. The variation in the SiO_2 indicates that Na_2O is partly present in the riebeckite molecule, and partly replaces CaO and (Mg, Fe)O in the $RO \cdot SiO_2$ molecule.

Micas (*Table XIV*).—For these, as already said, the chemical component associated with Al_2O_3 which may be transferred from the feldspathic minerals is K_2O, and for purposes of calculation it is convenient to compare other components with K_2O. The micas included in Table XIV are of three kinds — biotite proper, lepidomelane, and phlogopite.

a) For *biotite:*

Al_2O_3 ranges from 1.3 to 1.9, and the ratio of Fe_2O_3 to K_2O is 0.28 to 0.33, that is, nearly constant.

The ratio of $MgO + FeO$ to K_2O is 4.5 to 5.9 and magnesia is in excess of ferrous iron. The ratio of MgO to FeO is 1.1 to to 1.6. Average, 1.5.

The SiO_2 nearly conforms to the theoretical molecule $(K, H)_2O \,.\, (Al, Fe)_2O_3\ 2SiO_2 + n\ 2(Mg, Fe)O \,.\, SiO_2$.

b) For *lepidomelane:*

The ratio of Al_2O_3 to K_2O is nearly the same as in biotite, but that of Fe_2O_3 to K_2O is higher in two cases.

(Mg, Fe)O is lower, and ferrous iron dominates over magnesia.

c) For *phlogopite:*

The ratio of Al_2O_3 to K_2O is nearly the same as for biotite and lepidomelane, but that of Fe_2O_3 to K_2O is lower.

The ratio of $MgO + FeO$ to K_2O is nearly the same as in biotite, but magnesia greatly predominates over ferrous iron.

The ratio of SiO_2 to K_2O, although nearly the same as in biotite, does not conform to the formula given for biotite.

From these relations we may deduce the following method of transferring aluminous molecules from salic and non-aluminous molecules from femic to form molecules of augite, amphibole, and mica.

For the calculation of aluminous pyroxene: The kind of pyroxene to be calculated should depend upon the kind of rock in which it occurs.

a) If the femic minerals already calculated for the rock include acmite molecules, sufficient Na_2O and equal Fe_2O_3 are to be combined with diopside molecules to satisfy the ratio

$$\frac{Na_2O}{CaO} = D$$

(D standing for datum, the value given in the pyroxene or other mineral to be calculated); CaO in the ratio being equal to

CaO_d, in diopside, plus CaO_{an}, derived from anorthite, in consequence of the transfer of Al_2O_3 insufficient amount to satisfy the ratio

$$\frac{Al_2O_3}{CaO_d + CaO_{an}} = D\,.$$

Moreover, the ratio

$$\frac{(Mg,Fe)O}{CaO_d + CaO_{an}} = D\,,$$

approximately 1, must be maintained by transferring $(Mg,Fe)O$ from femic hypersthene or olivine. If the amount of these mineral is comparatively small a limit is set to the amount of aluminous pyroxene that can be produced.

b) If there are no acmite molecules estimated among the femic minerals, sufficient Na_2O must be transferred from soda-feldspathic molecules to satisfy the ratio

$$\frac{Na_2O}{CaO_d \pm CaO_{an}} = D\,,$$

where $\pm\, CaO_{an}$ is the lime transferred from, or to, anorthite. If transferred from anorthite to diopside the sign is $+$, if to anorthite from diopside the sign is $-$.

This follows from the fact that the transfer of Na_2O from soda-feldspathic molecules liberates equal molecules of Al_2O_3, and if all of these are not needed to satisfy the ratio

$$\frac{Al_2O_3}{CaO_d \pm CaO_{an}} = D\,,$$

as is the case in a number of pyroxenes given in Table XII, the Al_2O_3 not required withdraws CaO from diopside molecules to maintain the stoichiometric proportions obtaining in the salic minerals by making additional anorthite.

Fe_2O_3 is to be transferred from extra Fe_2O_3 (hematite) or from $FeO\,.\,Fe_2O_3$ (magnetite) in sufficient amount to satisfy the ratio.

$$\frac{Fe_2O_3}{CaO_d \pm CaO_{an}} = D\,.$$

The liberated FeO is to be added to sufficient (Mg, FeO) from hypersthene or olivine to maintain the ratio

$$\frac{(\mathrm{Mg,Fe})\mathrm{O}}{\mathrm{CaO_d} \pm \mathrm{CaO_{an}}} = \mathrm{D}\ .$$

When the sign of CaO_{an} is — the transfer of (Mg,Fe)O and the liberated FeO is to hypersthene or olivine from diopside.

A readjustment of SiO_2 is necessary according as (Mg,Fe)O is transferred from or to hypersthene or olivine, and as Na_2O is transferred from albite or nephelite. If there is extra SiO_2 it is placed first with the bases having strongest affinity for it unless these are already satisfied, when it appears as quartz.

In case the transfer is to be made to the complete exhaustion of one of the limiting components, the algebraic formulæ which can be devised for a particular case can be solved, but it frequently happens that augite occurs in rocks together with hypersthene or olivine, lime-soda-feldspars, and magnetite. The algebraic problem is indeterminable, since there are more unknown quantities than equations to satisfy them, unless the quantity of one or more of the minerals mentioned be given. More or less aluminous pyroxene within the limits of the magma appears to develop in different instances. The factors controlling the amount of augite crystallized in such cases are not at present known. The same statement may be made with reference to other aluminous ferromagnesian minerals.

For the calculation of aluminous amphiboles: a) *Hornblendes* contain more Al_2O_3 than Na_2O, and in the great majority of cases occur in rocks not having acmite molecules among the femic minerals.

To transform diopside molecules into those of hornblende sufficient Na_2O must be transferred from soda-feldspars, and enough CaO from anorthite with their equivalent Al_2O_3 to satisfy the ratios

$$\frac{\mathrm{Na_2O}}{\mathrm{CaO_d} + \mathrm{CaO_{an}}} = \mathrm{D} \quad \text{and} \quad \frac{\mathrm{Al_2O_3}}{\mathrm{CaO_d} + \mathrm{CaO_{an}}} = \mathrm{D}\ .$$

Furthermore

$$\frac{Fe_2O_3}{CaO_d + CaO_{an}} = D$$

must be satisfied by transferring Fe_2O_3 from Fe_2O_3 (hematite), or from $FeO.Fe_2O_3$ (magnetite).

The liberated FeO with (Mg,Fe)O from hypersthene or olivine must be transferred to satisfy the ratio

$$\frac{(Mg,Fe)O}{CaO_d + CaO_{an}} = D \ .$$

SiO_2 must be adjusted in the manner already indicated for the case of pyroxene.

b) The calculation of the more alkalic amphiboles which occur in rocks rich in soda and iron and comparatively poor in lime and magnesia is to be made in the following manner :

Sufficient acmite molecules are transferred to satisfy the ratio

$$\frac{Fe_2O_3}{CaO_d \pm CaO_{an}} = D \ .$$

Equal Na_2O from acmite plus sufficient Na_2O from soda feldspars is transferred to satisfy the ratio

$$\frac{Na_2O}{CaO_d \pm CaO_{an}} = D \ .$$

Al_2O_3 equal to Na_2O transferred from soda-feldspars is liberated and enough of it is transferred to amphibole to satisfy the ratio

$$\frac{Al_2O_3}{CaO_d \pm CaO_{an}} = D \ .$$

If all the liberated Al_2O_3 is not required to satisfy the last named ratio, CaO must be withdrawn from diopside to form additional anorthite, and the sign of CaO_{an} is minus.

If more Al_2O_3 than that liberated from soda feldspars is needed to satisfy the ratio in question additional Al_2O_3 with CaO is transferred from anorthite, and the sign of CaO in the expression is plus.

The ratio

$$\frac{(Mg,Fe)O}{CaO_d \pm CaO_{an}} = D$$

must be established as well as that of

$$\frac{MgO}{FeO} = D$$

since the latter is highly characteristic.

The adjustment of SiO_2 follows the ratio

$$\frac{SiO_2}{CaO_d \pm CaO_{an}} = D$$

and the requirements of the other molecules.

For the calculation of ferromagnesian mica.—The process is essentially the same for various kinds, the values of the ratios varying for biotite, lepidomelane, and phlogopite.

In most cases Al_2O_3 is in excess of K_2O, and in transferring K_2O from feldspathic molecules the accompanying equal Al_2O_3 is not sufficient to satisfy the ratio

$$\frac{Al_2O_3}{K_2O} = D\ .$$

Extra Al_2O_3 may be derived from corundum when estimated present, and this will be the case in numerous rocks in which muscovite and biotite have developed.

If there is no extra Al_2O_3 of this kind, Al_2O_3 must be transferred from anorthite until the ratio in question is satisfied. The liberated CaO must be transferred to diopside molecules.

Fe_2O_3 is to be transferred from Fe_2O_3 (hematite) or FeO. Fe_2O_3 (magnetite), and the liberated FeO is to be added to (Mg,Fe)O, to satisfy the ratio

$$\frac{Fe_2O_3}{K_2O} = D\ .$$

(MgFe)O must be transferred from hypersthene or olivine to satisfy the ratio

$$\frac{(Mg,Fe)O}{K_2O} = D\ ,$$

and the ratio $\frac{MgO}{FeO}$ must be maintained according to the kind of mica.

SiO_2 and TiO_2 are to be transferred according to their respective ratios

$$\frac{SiO_2}{K_2O} = D \text{ and } \frac{TiO_2}{K_2O} = D\ .$$

After which SiO_2 must be adjusted among the molecules affected. In general some SiO_2 will be liberated and the amount of quartz in quartz-bearing rocks will be increased. In other cases lower silicates will be raised.

The calculation of muscovite is simple, for the reason that it occurs mainly in rocks in which there is an excess of Al_2O_3, estimated as corundum.

Since in common muscovite $H = 2K$ the following ratios obtain:

$$\frac{H_2O}{K_2O} = 2\ , \quad \frac{Al_2O_3}{K_2O} = 3\ , \quad \frac{SiO_2}{K_2O} = 6\ .$$

Such a muscovite equals orthoclase plus corundum plus water.

$$2H_2O + K_2O + 3Al_2O_3 + 6SiO_2 = K_2O + Al_2O_3 + 6SiO_2 + 2Al_2O_3 + 2H_2O\ .$$

Hence to the molecules of hypothetical corundum add half as many of the orthoclase and an equal number of H_2O. The distribution of SiO_2 remains as before, the amount of quartz has not been affected.

From the foregoing it is seen that the development of augite in rocks reduces the amount of anorthite molecules calculated among the salic minerals and also reduces the amount of hypersthene or olivine that appear as femic. It affects the distribution of silica by liberating a part of that allotted to anorthite when the (Mg,Fe)O is derived from hypersthene, or when Na_2O is transferred from albite molecules. Its development would reduce the amount of olivine rather than hypersthene when both are otherwise normatively present.

The crystallization of hornblende reduces the amount of anorthite and hypersthene or olivine reckoned as standard minerals at a greater rate than that of augite would, in proportion to the amount of femic diopside molecules converted into hornblende, because the ratio of Al_2O_3 to CaO is higher, and the ratio of (Mg,Fe)O to CaO is twice as great as in augite. The effect on the SiO_2 would be similar.

The reduction of anorthite molecules by both these processes would affect the character of the plagioclase actually developed in the rock as compared with that reckoned as standard.

The development of mica would reduce the molecules of potash feldspar or of leucite, and the formation of biotite would also reduce the amount of hypersthene or olivine, and that of magnetite. It would reduce the amount of calculated corundum, or, in the absence of this extra Al_2O_3, would reduce the molecules of anorthite and increase those of diopside or wollastonite. The distribution of SiO_2 would be affected, and in cases where there is no extra Al_2O_3 and where (Mg,Fe)O is derived from hypersthene SiO_2 would be liberated to raise lower to higher silicates, or to form quartz.

Garnet.—In the matter of garnet it is easily seen that to form simple lime-alumina garnet (grossularite), $3CaO.Al_2O_3.3SiO_2$, it is necessary to combine anorthite molecules with femic wollastonite, $CaO.SiO_2$, with the liberation of silica. And it will be found that this garnet is frequently developed in rocks whose estimated standard minerals include wollastonite, and its crystallization reduces the amount of anorthite.

AN EXAMPLE OF CALCULATION.

As an illustration of the several processes above described we present the case of the Butte granite, because of its fairly uniform composition as shown by five analyses,[1] its distinct crystallization, which is of such size as to permit of accurate microscopical measurement, and because the two aluminous ferromagnesian minerals, biotite and hornblende, have been separated and analyzed. The rock from which these minerals were separated has been analyzed, and this analysis forms the basis for the calculation of the standard mineral composition. It is from Walkerville Station, near Butte, Mont. The thin section measured is from a specimen of very fresh rock taken near the surface twenty feet from the outcrop of the Parrot vein at Butte.

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[1] WEED, W. H., JOUR. GEOL., p. 739, 1899.

TABLE VII.

		Mol.	Pyr.	Ilm.	Ap.	Mag.	Orth.	Alb.	An.	Diop.	Hyp.	Qu'tz.
SiO_2.....	63.88	1.065	..	..	..	..	270	270	130	6	64	323
Al_2O_3...	15.84	.155	..	..	..	..	45	45	65	..	..	..
Fe_2O_3...	2.11	.013	..	..	..	13	..	..	..	3	..	..
FeO.....	2.59	.036	2	8	..	13	..	..	..		63	..
MgO.....	2.13	.053	..	..	..	..	..	..	..		..	..
CaO.....	3.97	.071	..	..	3	..	..	..	65	3	..	..
Na_2O....	2.81	.045	..	..	..	..	..	45	..	..	..	..
K_2O.....	4.23	.045	..	..	..	..	45	..	..	..	..	..
H_2O+...	.66	....	..	..	..	..	..	..	..	..	..	..
H_2O-...	.22	....	..	..	..	..	..	..	..	..	..	..
TiO_2.....	.65	.008	..	8	..	..	..	..	..	..	..	..
P_2O_5....	.21	.001	..	..	1	..	..	..	..	..	..	..
MnO.....	.07	.001	..	..	..	..	..	..	..	..	1	..
SrO......	.02	.000	..	..	..	..	..	..	..	..	..	..
BaO.....	.09	.000	..	..	..	..	..	..	..	..	..	..
Li_2O.....	tr	....	..	..	..	..	..	..	..	..	..	..
SO_3.....	.34	.004	4	..	..	..	..	..	..	..	..	..
Cl.......	tr	....	..	..	..	..	..	..	..	..	..	..
	99.82											

FORMULA.	MOL. WT.		NORM.		
SiO_2	323 × 60	quartz	19.38	Q	19.38
$K_2O.Al_2O_3.6SiO_2$	45 × 556	orthoclase	25.02	F	66.67
$Na_2O.Al_2O_3.6SiO_2$	45 × 524	albite	23.58		
$CaO.Al_2O_3.2SiO_2$	65 × 278	anorthite	18.07		
$CaO.SiO_2$	3 × 116	diopside	.67	P	7.45
$MgO.SiO_2$	2 × 100				
$FeO.SiO_2$	1 × 132				
$MgO.SiO_2$	51 × 100	hypersthene	6.78		
$FeO.SiO_2$	13 × 132				
$FeO.Fe_2O_3$	13 × 232	magnetite	3.01	M	4.24
$FeO.TiO_2$	8 × 152	ilmenite	1.22		
FeS_2	2 × 120	pyrite	.24	A	.55
$3CaO.P_2O_5$	1 × 310	apatite	.31		
		etc.	.99		
			99.27		

a) *The calculation of the standard minerals, or norm,* is expressed in Table VII. MnO is combined with FeO making 0.037 molecules. SO_3 is allotted to FeO to form FeS_2 becauseof the pyrite known to be present in the rock, TiO_2 to ilmenite, P_2O_5 to apatite, Fe_2O_3 to magnetite, K_2O to orthoclase, Na_2O to albite, the remaining Al_2O_3 (0.065 mol.) to anorthite, the remaining

CaO to diopside, the remaining (Mg,Fe)O to hypersthene, and the remaining SiO_2 to quartz. From the respective molecules the percentage weights are found by multiplying each by the molecular weight.

The classification of this rock from the data given in Table VII has been described on a previous page as an example of an intermediate rock.

b) *To calculate the mode* from the chemical analysis of the rock we have to introduce biotite and hornblende into the calculation, and we have the chemical analysis of each given in Tables XIII and XIV. We will assume that they contain all the magnesia (MgO) and all the iron oxide (FeO and Fe_2O_3), except that which goes into pyrite, magnetite and ilmenite. For these are the only ferromagnesian minerals observed in thin sections of the rock except a small amount of pyroxene intergrown with the hornblende. This was probably included in the hornblende material analyzed so that the analysis represents the mixture and may for the present calculation be treated as the composition of one mineral.

In Tables XIII and XIV are found the following ratios:

For *Butte hornblende:*

$$\frac{MgO}{CaO} = 1.53\,, \quad \frac{FeO}{CaO} = .71\,, \quad \frac{Al_2O_3}{CaO} = .32\,, \quad \frac{Fe_2O_3}{CaO} = .15\,,$$

$$\frac{Na_2O}{CaO} = .12\,, \quad \frac{SiO_2}{CaO} = 3.79\,.$$

For *Butte biotite:*

$$\frac{MgO}{K_2O} = 3.12\,, \quad \frac{FeO}{K_2O} = 1.96\,, \quad \frac{Al_2O_3}{K_2O} = 1.3\,, \quad \frac{Fe_2O_3}{K_2O} = .32\,,$$

$$\frac{H_2O}{K_2O} = .7\,, \quad \frac{SiO_2}{K_2O} = .6\,, \quad \frac{TiO_2}{K_2O} = .44\,.$$

If x=molecules of CaO in hornblende, y=molecules of K_2O in biotite, z=molecules of Fe_2O_3 in resulting magnetite, w= molecules of TiO_2 in resulting ilmenite,

Then $2.24x + 5.08y + z + w = 88 =$ (Total (Mg,Fe)O less FeO in pyrite).

$$.15x + .32y + z = 13 = (\text{Total } Fe_2O_3).$$

$$.44y + w = 8 = (\text{Total } TiO_2).$$

$$.32x + 1.3\,y = 12x + y + (x - 3) = (\text{transferred } Al_2O_3).$$

That is, the Al_2O_3 in hornblende and biotite equals the transferred soda, potash and transferred lime, which latter equals the CaO in hornblende less that previously allotted to dioside $(x-3)$. From these equations are derived the following values:

$$x = 8.4\ (8)\ ,\quad y = 12.4\ (12)\ ,\quad z = 7.8\ (8)\ ,\quad w = 2.5\ (3)\ .$$

From these values of x, y, z and w the readjustments for all the minerals are made as indicated in Table VIII.

TABLE VIII.

	Mol.	Pyr.	Ilm.	Mag.	Ap.	Orth.	Alb.	An.	Biot.	Horn.	Quartz.
SiO_2	1.065	.	.	.	.	198	264	120	72	30	381
Al_2O_3 ...	.155	.	.	.	.	33	44	60	16	2	...
Fe_2O_3 ...	.013	.	.	8	.	...	...	...	4	1	...
FeO	.036	2	3	8	.	...	...	...	19	4	...
MgO	.053	.	.	.	.	...	...	...	41	12	...
CaO	.071	.	.	.	3	...	...	60	..	8	...
Na_2O....	.045	.	.	.	.	...	44	...	..	1	...
K_2O	.045	.	.	.	.	33	...	...	12	..	...
H_2O+...	.....	.	.	.	.	...	...	...	8	..	...
H_2O- ...	.....	.	.	.	.	...	...	...	..	..	...
TiO_2	.008	.	3	.	.	...	...	...	5	..	...
P_2O_5	.001	.	.	.	1	...	...	...	..	..	...
MnO	.001	.	.	.	.	...	...	...	..	1	...
SO_3	.004	4	.	.	.	...	...	...	..	..	...
Etc......	.....	.	.	.	.	...	...	...	...	...	...

x = 8 = mol. CaO in hornblende.
y = 12 = mol. K_2O in biotite.
z = 8 = mol. Fe_2O_3 in magnetite.
w = 3 = mol. TiO_2 in ilmenite.

FORMULA.	MOL. WT.		MODE.
SiO_2	381 × 60	= quartz	22.86
$K_2O.Al_2O_3.6SiO_2$	33 × 556	= orthoclase	18.35
$Na_2O.Al_2O_3.6SiO_2$	44 × 524	= albite	23.06
$CaO.Al_2O_3.2SiO_2$	60 × 278	= anorthite	16.68
$8H_2O$	8 × 18	= biotite	10.92
$12K_2O$	12 × 94		
$16Al_2O_3$	16 × 102		
$4Fe_2O_3$	4 × 160		
$41MgO$	41 × 40		
$19FeO$	19 × 72		
$5TiO_2$	5 × 80		
$72SiO_2$	72 × 60		
$1Na_2O$	1 × 62	= hornblende =	3.56
$8CaO$	8 × 56		
$12MgO$	12 × 40		
$5FeO$	5 × 72		
$2Al_2O_3$	2 × 102		
$1FeO_3$	1 × 160		
$30SiO_2$	30 × 60		
$FeO.Fe_2O_3$	8 × 232	= magnetite =	1.86
$FeO.TiO_2$	3 × 152	= ilmenite =	.46
FeS_2	2 × 120	= pyrite =	.24
$3CaO.P_2O_5$	1 × 310	= apatite =	.31
		etc.	.85
			99.15

c) *The process of calculating the norm from the mode*, that is, the standard mineral composition from a microscopical investigation of rock sections, may be illustrated as follows :

Two thin sections of Butte granite were examined ; one from a surface excavation, twenty feet from the Parrott vein, very fresh, with almost no signs of alteration, the other from similar rock used in building in the city of Butte, the location of the quarry not noted.

In the first section an aggregate distance of 12,740 units of the micrometer scale was measured, embracing 604 measurements. The average diameter of the plagioclase crystals was 32 units, and the total length of plagioclase diameters was 5,492. Table IX shows the lengths, relative volumes, assumed specific gravities of each mineral, and the resulting percentages by weight.

TABLE IX.

	FIRST ROCK.				SECOND ROCK.	
	Total Diameters.	Relative Volumes.	Sp. gr.	Weights.	Relative Volumes.	Weights.
Quartz	2,954	23.17	2.65	22.55	20.97	20.34
Orthoclase	2,373	18.62	2.57	17.57	21.07	19.82
Plagioclase	5,492	43.10	2.68	42.47	42.29	41.48
Biotite	1,130	8.87	3.00	9.77	8.15	8.94
Hornblende	482	3.78	3.20	4.44	4.84	5.67
Pyroxene	252	1.97	3.30	2.37	2.07	2.50
Magnetite	51	.40	5.17	.76	.54	1.02
Pyrite	6	.04	5.00	.07	.02	.04
	12,740	99.95		99.98	99.95	99.81

In the second rock section examined an aggregate distance of 7,122 units of the scale was measured, embracing 403 measurements. The average diameter of the plagioclase was 24 units, and the total length of plagioclase diameters was 3,012. The relative volumes and weights are given in the last two columns of the Table.

A comparison of the two cases shows how closely the rocks resemble one another, the second being slightly higher in orthoclase and lower in quartz than the first. Other sections from

Butte granite from other localities in the vicinity of Butte show slightly more ferromagnesian minerals. Weed[1] has called attention to the generally uniform composition of this great body of granite as indicated by five chemical analyses, one of which is given in the tables of mica and hornblende. The specimen from near the Parrot vein will be made the basis of the following discussion.

Optical investigation of the plagioclase by the Michel-Lévy method with Carlsbad twins of albite twins showed that the central portion of each crystal has approximately the composition of Ab_1An_1, but the marginal zones are more sodic, having in some crystals the composition of oligoclase as indicated by the optical orientation and the relative index of refraction as compared with quartz by the Becke method. Without making the necessary observations for estimating the relative proportions of the several zones, and the average composition of the plagioclase as a whole, it was seen that the greater part of each crystal is about $Ab_1\ An_1$, and only a narrow margin is oligoclase, but the optical orientation of the outer portions shifts gradually in most cases from the central part to the margin. The average composition of the plagioclase is probably andesine somewhat more sodic than $Ab_1\ An_1$. If Ab_3An_2, it would have the composition of the mixture of albite and anorthite calculated from the chemical analysis of the Butte granite from Walkerville Station already cited, after developing biotite and hornblende. In this case the 42.47 per cent. of plagioclase would yield by molecular calculation 24.71 per cent: albite and 17.76 per cent. anorthite. In the second rock there would be 24.29 per cent. albite and 17.18 per cent. anorthite. The orthoclase may be considered as wholly potassic and reckoned as pure orthoclase.

In order to obtain the salic and femic components of the biotite, hornblende, and pyroxene, since the other minerals are standard, we may take the analysis of Butte biotite from Table XIV and multiply it by 0.0977, the percentage weight of biotite, and take the analysis of Butte hornblende from Table XIII and multiply it by 0.0681, the combined percentage weight of hornblende and pyroxene, for the reason already given. The resulting constituents reduced to molecular proportions may be distributed among salic and femic minerals as shown in the accompanying Table X.

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[1] Weed, W. H., Jour. Geol., Vol. VII, pp. 737–50.

From these data we deduce the standard mineral composition of the rock from near the Parrot vein as follows:

TABLE X.

	9.77 % Biot.	6.81% Hornbl.	Sum.	Fluor.	Ilm.	Mag.	Orth.	Alb.	An.	Diop.	Hyp.	Minus Qu'rtz
SiO_2	3.58	3.11	.111	..	..	..	66	6	12	12	64	−49
Al_2O_3	1.37	.46	.018	..	..	..	11	1	6	..	..	....
Fe_2O_3	.52	.34	.005	..	..	5	..	..	..	..	..	....
FeO	1.37	.71	.029	..	6	5	..	..	..	2	16	....
MgO	1.21	.82	.051	..	..	..	..	..	..	4	47	....
CaO	.00	.76	.014	2	..	..	..	..	6	6	..	....
Na_2O	.01	.05	.001	..	..	..	..	1	..	..	..	....
K_2O	.91	.08	.011	..	..	..	11	..	..	..	..	....
H_2O-	.12	.03	....	..	..	..	..	..	..	..	..	....
H_2O+	.36	.16	....	..	..	..	..	..	..	..	..	....
TiO_2	.35	.10	.006	..	6	..	..	..	..	..	..	....
P_2O_5	.01	.02	.000	..	..	..	..	..	..	..	..	....
MnO	.02	.04	.001	..	..	..	..	..	..	..	1	....
BaO	.01	....	....	..	..	..	..	..	..	..	..	....
Cl	.02	....	....	..	..	..	..	..	..	..	..	....
F	.07	.02	.004	4	..	..	..	..	..	..	..	....

FORMULA.	MOL. WT.		
SiO_2	49 × 60	= quartz =	2.94
$K_2O.Al_2O_3.6SiO_2$	11 × 556	= orthoclase =	6.12
$Na_2O.Al_2O_3.6SiO_2$	1 × 524	= albite =	.52
$CaO.Al_2O_3.2SiO_2$	6 × 278	= anorthite =	1.67
$CaO.SiO_2$	6 × 116	= diopside =	1.36
$MgO.SiO_2$	4 × 100		
$FeO.SiO_2$	2 × 132		
$MgO.SiO_2$	47 × 100	= hypersthene =	6.94
$FeO.SiO_2$	17 × 132		
$FeO.Fe_2O_3$	5 × 232	= magnetite =	1.16
$FeO.TiO_2$	6 × 152	= ilmenite =	.91
CaF_2	2 × 94	= fluorite =	.19

Percentages Determined from Rock.		Readjustments.		Standard Mineral Composition.	
Quartz	22.55		−2.94	Quartz	19.61
Orthoclase	17.57		+6.12	Orthoclase	23.69
Plagioclase	42.47	Albite 24.71	+ .52	Albite	25.23
		Anorthite 17.76	+1.67	Anorthite	19.43
Biotite	9.77	Diopside	1.36	Diopside	1.36
Hornblende	4.44	Hypersthene	6.94	Hypersthene	6.94
Pyroxene	2.37	Fluorite	.19	Fluorite	.19
		Ilmenite	.91	Ilmenite	.91
Magnetite	.76		+1.16	Magnetite	1.92
Pyrite	.07			Pyrite	.07
					99.35

The approximate chemical composition of this rock is found by separating each of the minerals observed in the rock into its chemical components. The results are given below:

TABLE XI.

	Biotite.	Hornblende and Pyroxene.	Magnetite.	Pyrite.	Anorthite.	Albite.	Orthoclase.	Quartz.	First Rock.	Second Rock.	Atlantic Mine.
SiO_2 ...	3.58	3.11	...	...	7.66	16.97	11.37	22.55	65.24	64.43	64.34
Al_2O_3 ..	1.37	.46	...	...	6.52	4.81	3.22	.....	16.38	16.46	15.72
Fe_2O_3 ..	.52	.34	.52	...	....	.....	.....	.....	1.38	1.57	1.62
FeO....	1.37	.71	.23	.04	....	.....	.....	.....	2.35	2.42	2.94
MgO...	1.21	.82	...	...	....	.....	.....	.....	1.93	2.10	2.17
CaO....	.00	.76	...	...	3.57	.....	.....	.....	4.33	4.38	4.24
Na_2O...	.01	.05	...	...	....	2.93	.....	.....	2.99	2.95	2.76
K_2O ...	.91	.08	...	...	....	.....	2.97	.....	3.96	4.27	4.04
H_2O-.	.12	.03	...	...	....	.....	.....	.....	.15	.15	.25
H_2O+.	.36	.16	...	...	....	.....	.....	.....	.52	.43	.76
TiO_2...	.35	.10	...	...	....	.....	.....	.....	.45	.35	.53
P_2O_5...	.01	.02	...	...	....	.....	.....	.....	.03	.04	.14
MnO...	.02	.04	...	...	....	.....	.....	.....	.06	.06	.12
SrO....	...	....	...	...	....	.....	.....	.....	...	...	.03
BaO....	.01	....	...	...	....	.....	.....	.....	.01	.01	.06
Cl......	.02	....	...	...	....	.....	.....	.....	.02	.02	.03[1]
F......	.07	.02	...	...	....	.....	.....	.....	.09	.09	.005[2]
S......	....	....	...	.04	....	.....	.....	.....	.04	.02	.03[3]
....	....	....	...	...	....	.....	.....	.....	.....	.....	.02[4]
									99.93	99.75	99.805

[1] CO_2 [2] Cu [3] FeS_2 [4] ZrO_2

The chemical composition of the second rock from Butte in which the minerals were measured is given in the same table, and also the analysis of Butte granite from the Atlantic Mine. The similarity of the results is an indication of the success of the process in this instance.

With the data here assembled it is possible to classify the rock from near the Parrot vein with almost as much accuracy as though it had been analyzed chemically. In other cases the data may not be so nearly correct, but the error in many cases will be quite within the limits of variation for the division of the classification to which the rock belongs.

It is evident that there is need for more chemical work upon the component minerals of igneous rocks and the correlation of their optical properties and chemical composition with that of the rocks containing them. The necessity is also apparent for complete analyses not only as to the main constituents, but also as regards some of the constituents hitherto considered as rare or of little importance, but which modern investigation has shown to be widely distributed and often of considerable influence on the norm and mode. The constituents present usually in small amounts are distributed very unequally among the various kinds of rock magmas, and it would save the careful analyst much needless labor if the petrographer would indicate to him those which it is advisable to look for and determine.

EPILOGUE.

Some who read this essay will, without doubt, object to the method of classification herein proposed because it is new and embodies new principles, since experience has shown that one's mental attitude toward new methods is on the whole conservative, and tends to resist their introduction. It is, also, easier to travel along a familiar and oft-trodden path, no matter how crooked and obstructed it may be, than to hew out a new one and provide a broader way for the future.

Objection will doubtless be made that the system, on account of the definite quantitative character of its divisions, throws a greater amount of mental responsibility in classifying upon the one who uses it. Thus, for instance, at the very outset, it will often happen that megascopically a rock will be so close to one of the lines separating two different classes that it will be difficult to know to which one it should be assigned. And it will sometimes happen that later chemical or microscopical investigation will show the preliminary classification to have been wrongly made. Moreover, when such examinations have been made, it will often occur that it is largely a matter of judgment as to which of two adjacent Orders, Rangs, or Grads a rock properly belongs.

To some this mental responsibility is distasteful and unsatisfactory; they desire a classification made up of a number of simple divisions like neat pigeon-holes or compartments into which each object can be easily and promptly thrust and docketed, and any method which fails to achieve this and relieve them of considerable mental effort in classifying rocks will not, in their estimation, be a proper one.

Unfortunately the difficulty in this respect lies not in the method, but is inherent in the subject itself. Rocks grade into one another in all directions, chemically, minerally, and texturally, and these again overlap in the different modes of geological occurrence.

Therefore, unless the future should reveal new properties of rocks, as yet unknown and unsuspected, which may be used as bases of classification, every method so far devised, or which can be devised, must have artificial lines of division, and cause the petrographer trouble in certain cases in deciding where his rocks belong. The erection of the monzonite group by Brögger is a good example of this. Where rocks contained about equal amounts of orthoclase and plagioclase it was formerly difficult to say whether they should be classed as syenites or diorites. The formation of the monzonite group avoided this difficulty. but in its turn gave rise to two others whose sum total is greater than the original one; for it is clear that it will be equally difficult now to decide whether a syenite with considerable plagioclase is still a syenite or a monzonite, and the same difficulty is met in diorites with considerable orthoclase. Thus, the formation of new groups simply multiplies the difficulty; it does not remove it.

The system which we propose does not, therefore, meet this trouble; it does not pretend to, for any system based on our present knowledge of rocks which should claim this would be in the nature of a mere nostrum, and would simply profess to do what it could not perform. In the ultimate analysis, every system will and must throw on the petrographer the mental responsibility of deciding, in a considerable number of cases, where rocks lie close upon divisional lines, into which of two divisions they must be put. He may not like this, but it cannot be avoided.

In different systems this difficulty is met in greater or lesser degree in different parts of the systems. In the one we propose it occurs chiefly in doubtful cases, at the beginning, and in the sum total we believe that it is less, or at all events no greater, than in any system heretofore proposed. But in regard to this each must judge for himself.

Objection may also be raised to this method of classification, that it entails a greater amount of labor upon the petrographer than those now in use. Perhaps there are some who, recalling the possibility of glancing through a microscope and noticing the presence of striated feldpars, with one or more dark-colored minerals, and promptly identifying the rock, regret the introduction of the chemical character of the feldspars and the quantitative determination of all the minerals. But to such we have no apology to make. Already precise optical methods of determining the feldspars are in use; and the confusion resulting from an absence of the quantitative element in rock definitions is becoming intolerable. The time has come when the petrographer should demand the exactness and sharpness of definition which, though obtained only by patient and careful work, add clearness to the conceptions and proportionate weight to the results of petrographic investigation.

It may be thought that the method of obtaining the approximate chemical composition of the magma by optical study and computation of the minerals in a rock is tedious, as it might possibly take several hours of work. But let one who considers this seriously make a good, careful, and accurate chemical analysis and note the amount of time consumed. We urge him not to throw the task on someone else, especially not on some beginner in analytical chemistry, as has unfortunately so often happened, but to make the analysis himself. Indeed, every petrographer should have made enough analyses to properly appreciate what they mean, after which we feel sure he will not object to the length of time involved in a microscopical analysis when one is possible.

Again, we have assumed as a condition for proper and convenient classification that it should be dichotomous, since not more than two factors can be handled advantageously at one time. To those who may not agree with this proposition we can only recommend the trial of forming a classification, using three or more factors at once. We have been through this phase of belief most thoroughly, and have convinced ourselves that two factors are all that can be handled at once without complications which would destroy the practical usefulness of any system. We believe that anyone who tries it will come to the same conclusion.

Furthermore, repeated trials have led us to think that a fivefold division is the most practicable one and the one best suited for the needs of petrography. We have applied this logically throughout, except in certain cases where a threefold seemed sufficient.

We desire also to ask the reader to bear in mind that the scheme of classification and nomenclature herein proposed is of much greater importance in some features than in others. The important points to bear in mind, and on which our system rests, are these:

a) The bringing together of rocks of *similar chemical composition* into the same divisions.

b) The resolution of a rock, either from its chemical or microscopical analysis, into quantitative amounts of certain *standard* minerals.

c) The establishment of a strictly *quantitative* basis of comparison of rock constituents, so that all constituents are valued according to their proportions.

d) The division of the minerals into two main groups, *salic* and *femic*, thus obtaining two factors, and the application of the fivefold division.

e) The recognition of the relation of the *mode* to the *norm*.

Time, use, and experience, if this system gains the currency we hope for it, may cause modifications in the smaller divisions; and the suggestions we have made in regard to nomenclature, both of rocks and of descriptive terms for their textures, may only in part be followed. But these are minor features and their importance is relatively small compared with the main points enumerated above. It is upon them that the system rests, and upon their adoption or rejection that it must either stand or fall.

The petrographer who believes that these fundamental points are correct and who is willing to accept them will not wish to reject the whole system because he may not agree with some of its minor features, but the one who does not accept the fundamental points will have no use for this system, or any of its features, great or small.

At first it will not be easy for the petrographer to think of rocks as expressed in this system ; it will require some use and experience. Nearly everywhere over the whole field it introduces new conceptions, and we firmly believe more correct and logical ones than have hitherto prevailed. We have made no attempt to modify, or patch up, or define the older previous systems, for we believe that the day for efforts of that kind has passed ; that they have had their use and should now be replaced by something more in accord with the results of the great amount of recent investigations, and of our present knowledge, and therefore better adapted to present and future needs. It is of course easier to patch and wear old garments than to make new ones, but to confess this fact as controlling one's attitude toward new propositions would be merely to acknowledge a condition of mental supineness.

If petrographers believe this system to be an advance over previous ones, we offer no apology for imposing a new mental burden upon them, for it is obvious that the ever-increasing accumulation of knowledge of the chemical and mineral properties of rocks, and of their relations to one another and to their texture, mode of occurrence, and their origin impose a greater task on modern petrographers than was borne by those of a former generation. And since it is not to be assumed that the present state of petrographical knowledge is complete, provision should be made for expansion and adjustment along lines which seem to be those in which future development will take place.

WHITMAN CROSS,
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TABLE XII. ANALYSES OF

	a		*b*		*c*		*d*		*e*		*f*		*g*		*h*	
	Rock.	Pyrox.	Rock.	Pyrox.	Rock.	Pyrox.	Rock.	Pyrox.	Pyrox.		Rock.	Pyrox.	Rock.	Pyrox.	Rock.	Pyrox.
SiO_2	50.23	50.86 .848	58.68	50.33 .839	61.93	50.63 .844	42.30	52.57 .876	52.20 .870	....	50.41	51.27 .854	67.42	53.19 .886	53.73	46.72 .779
Al_2O_3	11.22	none	19.50	.30 .003	13.18	.87 .008	12.63	1.33 .013	2.36 .022	....	12.30	3.05 .029	15.88	2.38 .023	20.35	2.41 .023
Fe_2O_3	3.34	1.19 .007	3.63	....	3.63	3.33 .020	15.48	5.86 .036	8.51 .053	....	5.71	3.08 .019	1.37	9.25 .057	3.74	17.29 .108
FeO	1.84	1.82 .025	2.58	12.37 .172	2.31	8.39 .116	5.07	3.23 .044	none	....	3.06	4.34 .060	1.14	5.15 .071	2.13	10.57 .147
MgO	7.09	17.42 .435	.79	10.98 .274	4.59	13.11 .325	5.24	12.36 .309	12.83 .321	....	8.69	14.21 .355	1.43	9.43 .236	.47	2.57 .064
CaO	5.99	23.32 .416	3.03	22.01 .393	3.48	21.30 3.80	8.42	18.49 .330	18.42 .329	....	7.08	22.58 .403	3.49	17.81 .318	2.72	13.51 .241
Na_2O	1.37	.76 .012	5.73	2.14 .034	2.67	1.02 .016	5.19	3.80 .061	2.56 .041	....	.97	.67 .010	6.42	2.63 .042	7.94	4.88 .079
K_2O	9.81	.42 .004	4.50	.94 .010	6.11	.50 .005	2.73	1.03 .011	.78 .008	....	7.53	.06 .000	2.65	.38 .004	6.05	.48 .005
H_2O+	1.72	.31	1.01	....	1.14	....	3.59	....	....	....	1.80	undet.	.05	.01	2.02	....
H_2O-	.93	....	....	....	....	....	....	....	....	....	.46	none		....	....	....
TiO_2	2.27	3.03	1.00	.66 .008	....	.79 .010	....	2.18 .024	3.12 .039	....	1.47	.70 .009	....	....	.09	trace
P_2O_5	1.89		.54	....	....	....	.65	....	....	....	.46	....	.07	....	....	....
SO_3	.74	....	....	....	....	....	....	....	....	....	none	....	....	....	....	....
Cl	.03	....	....	....	....	....	....	....	....	....	trace	....	....	....	.23	....
Cr_2O_3	.10	....	....	....	....	....	....	....	....	....	trace	none	....	....	....	....
NiO	....	....	....	....	....	....	....	....	....	....	.04	.03	....	....	....	....
MnO	.05	.03	....	....	....	....	.12	.15 .002	.12 .001	....	.15	.28 .004	trace	....	.51	1.31 .019
BaO	1.23	....	....	....	....	....	....	....	....	....	.23	none	....	....	....	....
SrO	.24									SrO	.06	none	....	....	....	....
Ce_2O_3 Di_2O_3	.03	....	....	....	....	....	....	....	....	ZrO_2	none	none	....	....	....	....
		99.16	100.99	99.73	99.04	99.84	101.42	101.00	100.90		100.42	100.27	99.92	100.23	99.98	99.74
	F. .50 100.62 22 100.40															
Sp. gr.	2.779 13°	....	....	3.401	....	....	2.974	3.227	3.268	....	2.88 29°	3.45 25°	....	....	....	....

a) *Diopside* from mixed wyomingite and madupite; rock analysis of *wyomingite* (felsophyro-wyomingose), Leucite Hills, Wyo. *A. J. S.*, Vol. IV (1897) p. 130.

b) *Diopside* (A. Merian) from *laurvikite* (grano-laurvikose) Byskoven near Laurvik, Norway. BRÖGGER, W. C., *Eruptivgesteine Kristianiageb*, Vol. III, pp. 23 and 31.

c) *Diopside* from pyroxene-granitite, Laveline, Vosges, Rosenbusch, El. Gest., p. 73; rock analysis of *augite-granitite* (grano-adamellose), Laveline, Vosges, ROSENBUSCH (v. Werveke), *Neues Jahrb. Min. und Pal.*, etc. (1881), Vol. I, p. 235.

d) *Augite*, c: **c**=39°30′, 2 H**a**=87°20′
e) *Augite*, c: **c**=34°, 2 H**a**=84°50′ (yellow)
from coarse grained nephelite-basalt (grano-malignose).
Katzenbuckel, Odenwald. ROSENBUSCH, *El. Gest.*, pp. 354, 357.

f) *Augite* from *syenitic-lamprophyre* (prowersose) Two Buttes, Colo. *Bull. 168*, *U. S. Geol. Surv.*, p. 165.

g) *Augite*, bottle green, in part colorless, with slight pleochroism, **a** and **b** bottle green, **c** yellowish green, **a** = **b** > **c**.

c: **a**=37° for colorless, c: **a**
Minn. *Am. Geol.*, Vol.

h) *Aegirite-augite* from *nepheli*
pp. 122, 126.

i) *Augite* from *shonkinite* (gra
(1895), pp. 410, 414.

j) *Augite* from *tinguaite* (?) (lau

k) *Aegirite-augite* from leucitoph

l) *Augite* from *analcite-basalt* (m
GEOL., Vol. V, p. 684.

m) *Augite*, yellow, c: **c**=39°, from
p. 357.

TABLE XI

			$\frac{Al_2O_3}{CaO}$	$\frac{Fe_2O_3}{CaO}$	$\frac{(NaK)_2O}{CaO}$	$\frac{MgO}{CaO}$	$\frac{FeO}{CaO}$	$\frac{SiO_2}{CaO}$	$\frac{TiO_2}{CaO}$
a) Diopside	phyro-wyomingose	Wyomingite	.00	.01	.03	1.04	.06	2.03	.09
b) Diopside	grano-laurvikose	Laurvikite	.00	.00	.11	.69	.44	2.13	.02
c) Diopside	grano-adamellose	Pyroxene-granitite	.02	.05	.05	.85	.31	2.22	.02
d) Augite	grano-malignose	Nephelite-basalt	.04	11	.21	.93	.14	2.66	.07
e) Augite	grano-malignose	Nephelite-basalt	.06	.16	.15	.97	.01	2.64	.12
f) Augite	prowersose	Syenitic lamprophyre	.07	.04	.03	.88	.16	2.11	.02
g) Augite	grano-lassenose	Augite soda granite	.07	.18	.14	.74	.22	2.78	.00
h) Aegirite-augite	grano-laurdalose	Nephelite-syenite	.09	.44	.34	.26	.61	3.23	.00
i) Augite	grano-shonkinose	Shonkinite	.10	.04	.05	.85	.19	2.06	.02
j) Augite	laurdalose	Tinguaite (?)	.10	.09	.06	.65	.24	2.05	.10

[1] All femic Ca, Mg, Fe calculated as metasilicate.

[2] Femic Ca, Mg, Fe calculated partly as orthosilicate and partly as metasilicate. Deficient SiO_2

PYROXENES AND THE ROCKS CONTAINING THEM.

i		*j*		*k*	*l*		*m*		*n*		*o*		*p*		*q*		*r*		
ock.	Pyrox	Rock.	Pyrox.	Pyrox.	Rock.	Pyrox.	Rock.	Pyrox.	Rock.	Pyrox.	Rock.	Pyrox.	Rock.	Pyrox.	Rock.	Pyrox.	Rock.	Pyrox.	Rock
6.73	49.42 .824	47.61	47.54 .792	46.47 .774	45.59	49.26 .821	42.46	44.55 .742	39.92	45.23 .754	42.78	44.65 .744	48.25	49.10 .818	43.74	44.55 .759	47.54	47.06 .784	47.
.05	4.28 .042	14.26	4.14 .040	4.28 .042	12.98	6.01 .059	18.49	7.27 .071	8.60	7.73 .075	8.66	6.62 .065	16.73	7.95 .078	14.82	7.86 .077	16.73	7.77 .076	16.
3.53	2.86 .018	4.90	5.64 .035	5.95 .037	4.97	3.31 .020	3.35	6.06 .038	4.40	2.95 .018	....	5.02 .031	3.99	trace	2.40	3.81 .024	6.69	1.30 .008	4.
3.20	5.56 .077	4.07	6.42 .089	12.17 .169	4. 70	4.23 .059	6.31	5.91 .082	8.00	4.07 .056	17.96	3.87 .054	6.28	8.30 .115	7.52	4.53 .063	6.67	8.15 .113	3.
.68	13.58 .339	2.62	10.05 .251	7.24 .181	8.36	12.40 .310	3.64	10.44 .261	20.17	12.25 .306	10.06	14.76 .369	5.77	12.37 .309	6.98	12.71 .318	6.38	13.52 .338	5.
3.22	22.35 .399	8.71	21.57 .385	19.23 .343	11.09	21.79 .389	8.70	22.83 .407	10.68	23.37 .417	12.29	20.32 .363	8.32	22.54 .402	10.81	20.84 .336	8.74	19.33 .345	10.
.81	1.04 .017	6.70	1.38 .022	2.61 .042	4.53	.79 .012	7.12	1.47 .023	1.91	.47 .007	2.31	1.29 .021	3.24	trace	3.08	1.29 .021	2.81	.33 .005	4.4
.76	.38 .004	4.08	.12 .001	.74 .008	1.04	.41 .004	4.58	.52 .006	1.03	.12 .001	.62	.49 .005	4.08	trace	2.90	.49 .005	1.10	.11 .001	4.
.24	.09	1.89	undet.	....	3.40	undet.	2.31	....	1.45	.37	3.96	....	1.72	....	2.94	....	.36	.20	.2
....	....	.26	none	....	.51	undet.	....	....	.43	....	....	....	....	....	....	....	....	....	...
.78	.55 .007	1.38	3.00 .037	.73 .009	1.32	1.53 .019	....	1.36 .019	2.70	4.28 .053	.28	2.93 .037	.89	(?)	2.80	2.85 .036	2.76 .51	1.82 .023	2.2
.51	....	1.38	....	....	.91	....	....	....	.51	none	....	....	.68	....	.64	....	....	.06	1.3
....	....	1.17	....	....	....	....	2.44	....	....	....	....	....	.12	....	.....	....	....	....	...
.18	....	.37	....	....	.05	....	.52	....	trace	....	....	....	.08	....	....	....	....	....	...
....	....	trace ?	trace ?	....	....	....	....	....	.14	....	....	....	....	....	....	....	....	trace	...
....	....	trace	trace	....	....	....	....	....	.06	.05	trace	....	....	....	....	....	....	trace	...
.28	.10 .001	.30	.36 .005	....	.14	undet.	....	....	.24	.07 .001	.95	....	trace	....	....	.38 .005	.19	.20 .003	trac
....	....	.41	none	....	.13	?	....	....	.06	none	....	....	.01	....	....	....	.03	....	...
....	....	.36	none	....	.12	.06	....	....	.04	none	....	....	....	....	....	....	....	....	...
....	....	.18 S .03	none	....	.03	....	....	....	none S. trace V_2O_3.04	....	....	....	....	....	$CO_2$1.5	....	....	....	...
.97	100.21	100.68	100.21	99.42	99.87	99.79	99.92	100.41	F. .07	100.96	99.87	99.95	100.16	100.26	100.23	99.31	100.51	99.85	100.42
									100.45 .03 100.42										
...	....	2.79	3.43	....	....	....	....	3.416	....	....	2.829	3.411	....	....	2.914	3.284	....	....	2.85
...	....	25°	28°	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	...

=22° for green, from *augite-soda-granite* (grano-lassenose) Kekequabic Lake,
XI (1893), p. 385.
te-syenite (grano-laurdalose), Zwart Koppies, Transvaal, Rosenbusch, *El. Gest.*,

no-shonkinose), Square Butte, Mont. Pirsson, *Bull. Geol. Soc. Am.*, Vol. VI

rdalose), Two Buttes, Colo. *Bull. 168 U. S. Geol. Surv.*, p. 165.
yre, Burgberg, near Rieden. Rosenbusch, *El. Gest.*, p. 278.
onchiquose), The Basin, Colo. *Bull. 168 U. S. Geol. Surv.*, p. 146, and Jour.

nephelinite (hauynophyre) (vulturose), Melfi, Italy. Rosenbusch, *El. Gest.*,

n) *Augite* from *nephelite-basalt* (uvaldose), Black Mountain, Uvalde county, Te
Surv., p. 63.
o) *Augite* from *limburgite*, Limburg, Kaiserstuhl. Rosenbusch, *El. Gest.*, p. 363.
p) *Augite* from *dolerite* (shoshonose), Valmont, Colo. *Bull. 150 U. S. Geol. Surv.*,
Geol. Surv., p. 140.
q) *Augite* from *monchiquite* (ourose), Rio do Ouro, Serra de Tingua, Rio de Janeiro.
234, 235.
r) *Augite* from *basalt* (auvergnose), six miles N. E. of Grants, N. M. *Bull. 168 U.*
s) *Augite* (c: c=54°) from *leucite-tephrite* (monchiquose), Falkenberg, near Tetsc
El. Gest., p. 346.
t) *Aegirite* from *nephelite-syenite* (grano-janeirose), Barreros, rock analysis from tunn
Serra do Poços de Caldas, Las Paolo, Brazil. Rosenbusch, *El Gest.*, pp. 122

Ia. MOLECULAR RATIOS IN PYROXENES.

emic	Salic	Deficient SiO_2				$\frac{Al_2O_3}{CaO}$	$\frac{Fe_2O_3}{CaO}$	$\frac{(NaK)_2O}{CaO}$	$\frac{MgO}{CaO}$	$\frac{FeO}{CaO}$	$\frac{SiO_2}{CaO}$	TiC Ca
.00	.00	......	*k*) Augite	no analysis	Leucitophyre	.12	.10	.14	.52	.49	2.25	.
.00	.00	......	*l*) Augite	monchiquose	Analcite-basalt	.15	.05	.04	.79	.16	2.11	.
.986[1]	.014	—.017	*m*) Augite	vulturose	Nephelinite	.17	.09	.07	.64	.20	1.82	.
.95[1]	.05	.000	*n*) Augite	uvaldose	Nephelite-basalt	.18	.04	.02	.73	.14	1.80	.1
.88[1]	.12	.000	*o*) Augite	(poor analysis)	Limburgite	.18	.08	.07	1.01	.15	2.05	.1
.91[1]	.09	.000	*p*) Augite	shoshonose	Dolerite	.19	...	...	.77	.28	2.03	..
.83[1]	.17	.000	*q*) Augite	ourose	Monchiquite	.22	.07	.07	.94	.20	2.26	.1
.87[1]	.13	.000	*r*) Augite	auvergnose	Basalt	.22	.02	.02	.98	.33	2.27	.7
.90[1]	.10	—.038	*s*) Augite	monchiquose	Leucite-tephrite	.22	.11	.06	.70	.14	1.95	.
.80[1]	.14	.000	*t*) Aegirite	grano-janeirose	Eleolite-syenite	.23	2.16	2.02	.38	.76	11.31	.

is that required to raise part of the salic components to leucite or nephelite.

OCKS CONTAINING THEM.

l		*m*		*n*		*o*		*p*		*q*		*r*		*s*		*t*	
k.	Pyrox.	Rock.	Pyrox.	Rock.	Pyrox.	Rock.	Pyrox.	Rock.	Pyrox.	Rock.	Pyrox.	Rock.	Pyrox.	Rock.	Pyrox.	Rock.	Pyrox.
59	49.26 .821	42.46	44.55 .742	39.92	45.23 .754	42.78	44.65 .744	48.25	49.10 .818	43.74	44.55 .759	47.54	47.06 .784	47.83	45.67 .761	52.75	51.60 .860
98	6.01 .059	18.49	7.27 .071	8.60	7.73 .075	8.66	6.62 .065	16.73	7.95 .078	14.82	7.86 .077	16.73	7.77 .076	16.09	9.04 .088	22.55	1.92 .018
97	3.31 .020	3.35	6.06 .038	4.40	2.95 .018	....	5.02 .031	3.99	trace	2.40	3.81 .024	6.69	1.30 .008	4.32	7.46 .046	3.65	26.29 .164
70	4.23 .059	6.31	5.91 .082	8.00	4.07 .056	17.96	3.87 .054	6.28	8.30 .115	7.52	4.53 .063	6.67	8.15 .113	3.62	2.00 .028	....	4.20 .058
36	12.40 .310	3.64	10.44 .261	20.17	12.25 .306	10.06	14.76 .369	5.77	12.37 .309	6.98	12.71 .318	6.38	13.52 .338	5.53	12.09 .302	.15	1.15 .029
09	21.79 .389	8.70	22.83 .407	10.68	23.37 .417	12.29	20.32 .363	8.32	22.54 .402	10.81	20.84 .336	8.74	19.33 .345	10.68	21.78 .389	1.85	4.25 .076
53	.79 .012	7.12	1.47 .023	1.91	.47 .007	2.31	1.29 .021	3.24	trace	3.08	1.29 .021	2.81	.33 .005	4.46	1.25 .020	8.10	8.89 .143
04	.41 .004	4.58	.52 .006	1.03	.12 .001	.62	.49 .005	4.08	trace	2.90	.49 .005	1.10	.11 .001	4.05	.56 .006	7.05	1.05 .011
40	undet.	2.31	....	1.45	.37	3.96	....	1.72	....	2.94	....	.36	.20	.24	.31	3.60	.56
51	undet.	....	....	.43	....	....	....	....	....	....	....	....	....	....	....	....	....
32	1.53 .019	....	1.36 .019	2.70	4.28 .053	.28	2.93 .037	.89	(?)	2.80	2.85 .036	2.76 .51	1.82 .023	2.27	.62 .008	....	....
91	....	....	....	.51	none	....	....	.68	....	.64	....	....	.06	1.33	....	....	....
..	....	2.44	....	....	....	....	....	.12	....	.....	....	....	....	....	....	....	....
05	....	.52	....	trace	....	....	....	.08	....	....	....	....	....	....	....	....	....
..	....	....	....	.14	....	....	....	....	....	....	....	....	trace	....	....	....	....
..	....	....	....	.06	.05	trace	....	....	....	....	....	....	trace	....	....	....	....
14	undet.	....	....	.24	.07 .001	.95	....	trace	....	....	.38 .005	.19	.20 .003	trace	....	....	....
13	?	....	....	.06	none	....	....	.01	....	....	....	.03	....	....	....	....	....
12	.06	....	....	.04	none	....	....	....	....	....	....	....	....	....	....	....	....
03	....	....	....	none S. trace V_2O_3.04	....	....	....	....	....	$CO_2$1.5	....	....	....	....	....	....	....
7	99.79	99.92	100.41	F. .07	100.96	99.87	99.95	100.16	100.26	100.23	99.31	100.51	99.85	100.42	100.78	99.70	99.91
				100.45 .03 100.42													
..	....	....	3.416	....	....	2.829	3.411	....	....	2.914	3.284	....	....	2.858	3.37	....	....
..	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....

rano-lassenose) Kekequabic Lake,

Transvaal, ROSENBUSCH, *El. Gest.*,

, *Bull. Geol. Soc. Am.*, Vol. VI

eol. Surv., p. 165.

Gest., p. 278.

S. Geol. Surv., p. 146, and JOUR.

i, Italy. ROSENBUSCH, *El. Gest.*,

n) *Augite* from ***nephelite-basalt*** (uvaldose), Black Mountain, Uvalde county, Texas. *Bull. 168 U. S. Geol. Surv.*, p. 63.

o) *Augite* from *limburgite*, Limburg, Kaiserstuhl. ROSENBUSCH, *El. Gest.*, p. 363.

p) *Augite* from *dolerite* (shoshonose), Valmont, Colo. *Bull. 150 U. S. Geol. Surv.*, p. 264, and *Bull. 168 U. S. Geol. Surv.*, p. 140.

q) *Augite* from *monchiquite* (ourose), Rio do Ouro, Serra de Tingua, Rio de Janeiro. ROSENBUSCH, *El. Gest.*, pp. 234, 235.

r) *Augite* from *basalt* (auvergnose), six miles N. E. of Grants, N. M. *Bull. 168 U. S. Geol. Surv.*, p. 170.

s) *Augite* ($c : \mathfrak{c} = 54°$) from *leucite-tephrite* (monchiquose), Falkenberg, near Tetschen, Bohemia. ROSENBUSCH, *El. Gest.*, p. 346.

t) *Aegirite* from ***nephelite-syenite*** (grano-janeirose), Barreros, rock analysis from tunnel between Prata and Cascada, Serra do Poços de Caldas, Las Paolo, Brazil. ROSENBUSCH, *El Gest.*, pp. 122, 126.

YROXENES.

		$\frac{Al_2O_3}{CaO}$	$\frac{Fe_2O_3}{CaO}$	$\frac{(NaK)_2O}{CaO}$	$\frac{MgO}{CaO}$	$\frac{FeO}{CaO}$	$\frac{SiO_2}{CaO}$	$\frac{TiO_2}{CaO}$	Femic	Salic	Deficient SiO_2
no analysis	Leucitophyre	.12	.10	.14	.52	.49	2.25	.02	$.88^1$	.12	—.013
monchiquose	Analcite-basalt	.15	.05	.04	.79	.16	2.11	.05	$.82^1$	.18	.000
vulturose	Nephelinite	.17	.09	.07	.64	.20	1.82	.04	$.82^1$	.18	—.053
uvaldose	Nephelite-basalt	.18	.04	.02	.73	.14	1.80	.13	$.81^1$	.19	—.039
(poor analysis)	Limburgite	.18	.08	.07	1.01	.15	2.05	.10	$.84^2$	.16	—.046
shoshonose	Dolerite	.19	...	...	.77	.28	2.03	...	$.81^2$	.19	—.036
ourose	Monchiquite	.22	.07	.07	.94	.20	2.26	.10	$.82^1$	.18	—.067
auvergnose	Basalt	.22	.02	.02	.98	.33	2.27	.70	$.79^2$	.21	.000
monchiquose	Leucite-tephrite	.22	.11	.06	.70	.14	1.95	.02	$.76^1$	.24	—.028
grano-janeirose	Eleolite-syenite	.23	2.16	2.02	.38	.76	11.31	.00	$.86^1$	.14	.000

ents to leucite or nephelite.

TABLE XIII. ANALYSES OF AMPHIBOLES AND THE ROC

	a		*b*		*c*		*d*		*e*		*f*		*g*	*h*		*i*	
	Rock.	Hornbl.	Rock.	Hornbl.	Rock.	Hornbl.	Rock.	Hornbl.	Rock.	Hornbl.	Rock.	Hornbl.	Hornbl.	Rock.	Hornbl.	Hast-ingsite.	Roc
SiO_2	66.83	47.49 .791	63.88	45.73 .762	62.21	45.76 .762	54.64	50.08 .835	47.27	46.08 .768	59.22	39.62 .660	41.35 .689	59.37	46.22 .770	34.18 .569	56.4
Al_2O_3	15.24	7.07 .069	15.84	6.77 .066	15.60	8.80 .086	12.06	7.97 .078	20.82	10.52 .103	13.59	14.92 1.46	13.48 .132	17.92	8.12 .079	11.52 .113	20.0
Fe_2O_3	2.73	4.88 .030	2.11	4.94 .031	5.26	5.32 .033	1.81	2.69 .016	1.85	2.81 .017	5.55	10.28 .094	5.14 .032	6.77	9.33 .058	12.62 .079	1.3
FeO	1.66	10.69 .148	2.59	10.39 .144	1.36	11.23 .156	5.03	6.71 .093	4.26	8.30 .101	4.03	7.67 .106	10.33 .143	2.02	15.18 .210	21.98 .305	4.3
MgO	1.63	13.06 .326	2.13	12.32 .308	2.61	14.08 .352	11.86	16.31 .408	6.44	14.40 .360	1.66	11.32 .283	11.44 .286	1.83	5.20 .130	1.35 .034	.6
CaO	3.59	11.92 .213	3.97	11.25 .201	6.55	10.62 .189	7.74	11.21 .200	13.02	12.64 .226	5.13	12.65 .226	10.93 .195	4.16	10.08 .180	9.87 .176	2.1
Na_2O	3.10	.75 .012	2.81	.77 .012	2.50	1.39 .022	2.35	1.22 .019	2.75	1.62 .026	5.31	1.12 .018	2.10 .034	1.24	2.46 .039	3.29 .053	5.6
K_2O	4.46	.49 .005	4.23	1.22 .013	1.63	.26 .003	1.01	.46 .005	.22	.34 .004	4.64	2.18 .023	.62 .007	6.68	1.23 .012	2.29 .024	7.1
H_2O+	.56	1.86	.66	2.29	2.25	.85	2.44	1.40	1.27	1.97	1.25	.48	.48	.38	1.36	.35	1.5
H_2O-	none	....	.22	.49	....	....	.12	....	.08	.17	....	....	....	....	....	....	.2
CO_2	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	...
TiO_2	.54	1.21 .015	.65	1.43 .018	....	1.43 .018	.61	.76 .009	.92	.77 .009	....	.19 .002	4.97 .062	.26	1.08 .013	1.53 .019	.2
P_2O_5	.18	none	.21	.35 .002	....	....	.08	trace	.74	.18	....	....	....	.58	....	....	.1
SO_3	....	....	.34	....	....	....	....	....	....	....	....	....	....	....	....	....	...
Cl	.02	....	trace	....	....	....	....	....	trace	....	....	....	....	....	....	....	.4
Cr_2O_3	....	none	....	....	....	....	....	.16	trace	....	....	....	....	....	....	....	...
NiO	....	.02	....	....	....	....	.05	....	....	....	....	....	....	....	....	....	trac
MnO	.10	.51 .007	.07	.54 .008	....	.57 .008	.13	.49 007	trace	.15 .002	....	.24 .003	....	....	....	.63 .009	.0
BaO	.11	none	.09	none	....	....	.05	none	....	....	....	....	....	...	....	....	...
SrO	.03	none	.02	none	....	....	trace	....	trace	....	....	....	....	...	....	....	...
ZrO_2	.04	F.06	....	....	....	....	V_2O_3.03	....	V_2O_3.02	.04	....	....	....	....	....	....	...
	100.82	V_2O_3.04	99.82	F. .28 .015	99.97	100.31	100.01	100.46	99.86	99.99	100.38	100.67	100.84	101.21	100.26	99.61	100.. .
		100.05 .02		98.77 .12	Sp. Gr..	3.212					2.74	3.266	3.25	2.710	3.157	3.433	100.
		100.03		98.65													

*Al_2O_3 and TiO_2 estimated from rock analysis. Al_2O_3 determined as 17.65 in

a) *Hornblende* from quartz-monzonite, S. E. Mt. Hoffmann, Cal.; rock analysis from *quartz-monzonite* (grano-toscanose), Nevada Falls Trail, Yosemite Valley, Cal. (average rock of region). *Bull. 168 U. S. Geol. Surv.*, p. 208, and *A.J.S.*, Vol. VII;(1899), p. 297.

b) *Hornblende* from *quartz-monzonite* (grano-amiatose), Walkerville Station, Butte, Mont. *Bull. 168, U. S. Geol. Surv.*, p. 116.

c) *Hornblende* (green) from *dacite*, Grenatilla, rock analysis from *hornblende-dacite* (bandose), San Pedro, Sierra del Cabo, Cabo de Gata, Spain, ROSENBUSCH, *El. Gest.*, pp. 285, 286.

d) *Hornblende* from *quartz-diorite* (grano-camptonose), 46 miles south of Table Mountain, Cal. *Bull. 168 U. S. Geol. Surv.*, p. 190.

e) *Hornblende* from *hornblende-gabbro* (grano-hessose), Beaver Creel Tree Quadrangle, Cal. *A. J. S.*, Vol. VII (1899), p. 297.

f. *Hornblende* from *andesite* (umptekose), Stenzelberg, Siebenge ROSENBUSCH, *El. Gest.*, pp. 290, 292.

g. *Hornblende* from "hornblende-diabase," Gräveneck, near We ROSENBUSCH, *El. Gest.*, p. 306.

h) *Hornblende* from *syenite*, Biella, Piedmont, Italy, ROSENBUSCH, *El.* pp. 103, 106.

i) *Hastingsite* (deep blue) from *nephelite-syenite*, Dunganon, O ROSENBUSCH, *El. Gest.*, p. 122.

j. *Barkevikite* from *sodalite-syenite* (grano-pulaskose), Square Butte, *A. J. S.*, Vol. XLV, 1893, p. 292.

TABLE XIIIa. MOLECULAR RATIOS IN AMPHIB

Minerals.	Rocks.		$\frac{Al_2O_3}{CaO}$	$\frac{Fe_2O_3}{CaO}$	$\frac{(Na,K)_2O}{CaO}$	$\frac{MgO}{CaO}$	(
a Hornblende	grano-toscanose	Quartz-monzonite	.32	.14	.08	1.53	
b Hornblende	grano-amiatose	Quartz-monzonite.	.32	.15	.12	1.53	
c Hornblende	grano-bandose	Dacite.	.45	.17	.13	1.86	
d Hornblende	grano-camptonose	Quartz-diorite	.39	.08	.12	2.04	
e Hornblende	grano-hessose	Gabbro	.45	.07	.13	1.60	
f Hornblende	grano-umptekose	Andesite (?) trachyte	.64	.41	.18	1.25	
g Hornblende	no analysis	Diabase	.67	.16	.21	1.46	
h Hornblende	(?) analysis	Syenite.	.44	.32	.28	.72	1
i Hastingsite	no analysis	Nephelite-syenite	.64	.45	.43	.33	1
j Barkevikite	grano-pulaskose	Sodalite-syenite.	.85	.12	.35	.19	1
k Riebeckite	grano-liparose	Soda granite	.23	1.9	2.18	.0	4
l Katophorite	no analysis	Sanidinite	.46	.66	1.23	.70	3
m Arfvedsonite	no analysis	Nephelite-syenite	.51	.29	1.71	.24	5
n Ainigmatite	felso-varingose	Pantellerite.	1.3	1.3	2.4	.58	12
o Ainigmatite	no analysis	Nephelite-syenite.	1.3	1.5	4.6	.33	20
p Amphibole	felso-liparose	Comendite	27.0	18.0	93.0	2.0	192

[1] All Femic Ca, Mg, Fe, calculated as metasilicate. [2] Femic Ca, Mg, Fe, calculated partly as ortho

Deficient SiO_2 is that required to raise part of the salic components to leucite or nephelite.

OF AMPHIBOLES AND THE ROCKS CONTAINING THEM.

f		*g*	*h*		*i*	*j*		*k*		*l*	*m*	*n*		*o*	*p*	
Rock.	Hornbl.	Hornbl.	Rock.	Hornbl.	Hastingsite.	Rock.	Barkevikite.	Rock.	Riebeckite.	Katophorite.	Arfvedsonite.	Rock.	Cossyrite.	Ainigmatite.	Rock.	Amphibole.
59.22	39.62 .660	41.35 .689	59.37	46.22 .770	34.18 .569	56.45	38.41 6.40	73.93	49.65 .827	45.53 .759	43.85 .731	70.30	43.55 .726	37.92 .632	74.76	49.10 .818
13.59	14.92 1.46	13.48 .132	17.92	8.12 .079	11.52 .113	20.08	16.39 * .160	12.29	1.34 .013	4.10 .040	4.45 .043	6.32	4.96 .048	3.23 .031	11.60	5.50 .054
5.55	10.28 .094	5.14 .032	6.77	9.33 .058	12.62 .079	1.31	3.75 .023	2.91	17.66 .110	9.35 .058	3.80 .024	9.23	7.97 .045	5.81 .036	3.50	4.20
4.03	7.67 .106	10.33 .143	2.02	15.18 .210	21.98 .305	4.39	21.75 .302	1.55	19.55 .271	23.72 .301	33.43 .464	1.40	32.87 .456	35.88 .498	.19	27.70 .385
1.66	11.32 .283	11.44 .286	1.83	5.20 .130	1.35 .034	.63	2.54 .063	.04	....	2.46 .061	.81 .020	.89	.86 .021	.33 008	.18	.17 .004
5.13	12.65 .226	10.93 .195	4.16	10.08 .180	9.87 .176	2.14	10.52 .188	.31	3.16 .056	4.89 .087	4.65 .083	.84	2.01 .036	1.36 .024	.07	.13 .002
5.31	1.12 .018	2.10 .034	1.24	2.46 .039	3.29 .053	5.61	2.95 .047	4.66	7.61 .122	6.07 .098	8.15 .131	7.70	5.29 .085	6.58 .106	4.35	10.50 .169
4.64	2.18 .023	.62 .007	6.68	1.23 .012	2.29 .024	7.13	1.95 .020	4.63	....	.88 .009	1.06 .011	2.50	.33 .003	.51 .005	4.92	1.60 .017
1.25	.48	.48	.38	1.36	.35	1.51	.24	....	1.67	....	.15	.82	....	....	.64	....
....	....	....	....	....	....	.26	....	.41	....	....	....	....	....	....	....	...
....	....	....	....	....	....	....	....	....	....	....	...	....	....	....	....	....
....	.19 .002	4.97 .062	.26	1.08 .013	1.53 .019	.29	1.26* .018	.18	....	....	....	....	....	7.57 .094	trace	....
....	....	....	.58	....	....	.13	....	....	....	....	....	....	....		trace	....
....	....	....	....	....	....	....	....	....	....	...	....	. ..	....		....	....
....	....	....	....	....	....	. .43		....	....	....	....	....	....	....	...	....
....	....	....	....	....	....	....		....	....	....	....	....	....	....	....	....
....	....	....	....	...	....	trace	trace	....	....	....	....	....	....	....	....	....
....	.24 .003	....	....	....	.63 .009	.09	.15 .002	trace	....	2.96 .041	.45 .006	....	1.98 .027	.100 .013	....	.50 .007
....	....	....	...	....	....	....	....	none	....	....	....	....	....	....	....	....
....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	...	....
....	....	....	....	....	....	....	....	....	....	....	....	....	CuO.39	. ..	....	...
100.38	100.67	100.84	101.21	100.26	99.61	100.45 .10	99.91	100.91	100.64	99.96	100.80	100.00	100.21	100.19	100.21	99.40
2.74	3.266	3.25	2.710	3.157	3.433	100.35	3.437	2.642		3.43	3.44		3.74 3.75	3.80 3.852	....	....

estimated from rock analysis. Al_2O_3 determined as 17.65 including TiO_2.

nde from *hornblende-gabbro* (grano-hessose), Beaver Creek, Big e Quadrangle, Cal. *A. J. S.*, Vol. VII (1899), p. 297.

nde from *andesite* (umptekose), Stenzelberg, Siebengebirge, ENBUSCH, *El. Gest.*, pp. 290, 292.

nde from "hornblende-diabase," Gräveneck, near Weilberg. ENBUSCH, *El. Gest.*, p. 306.

nde from *syenite*, Biella, Piedmont, Italy, ROSENBUSCH, *El. Gest.*, 103, 106.

site (deep blue) from *nephelite-syenite*, Dunganon, Ontario, ENBUSCH, *El. Gest.*, p. 122.

ite from *sodalite-syenite* (grano-pulaskose), Square Butte, Mont. . *S.*, Vol. XLV, 1893, p. 292.

k) *Riebeckite from granite* (grano-liparose), Quincy, Blue Hills, Mass., *A. J. S.*, Vol. VI, 1898, p. 181.

l) *Katophorite* from *sanidinite*, San Miguel, Azores, ROSENBUSCH, *El. Gest.*, p. 266.

m) *Arfvedsonite* from *nephelite-syenite*, Kangerdluarsuk, Greenland, ROSENBUSCH, *El. Gest.*, p. 122.

n) *Cossyrite* (ainigmatite) from *pantellerite* (felso-varingose) Khartibugal, Pantellaria, ROSENBUSCH, *El. Gest.*, p. 257.

o) *Ainigmatite* from *nephelite-syenite*, Julianehaab, Greenland, ROSENBUSCH, *El. Gest.*, p. 122.

p) *Amphibole* from *comendite* (felso-liparose), San Pietro, Sardinia, ROSENBUSCH, *El. Gest.*, p, 257.

IIIa. MOLECULAR RATIOS IN AMPHIBOLES.

	$\frac{Al_2O_3}{CaO}$	$\frac{Fe_2O_3}{CaO}$	$\frac{(Na,K)_2O}{CaO}$	$\frac{MgO}{CaO}$	$\frac{FeO}{CaO}$	$\frac{SiO_2}{CaO}$	$\frac{TiO_2}{CaO}$	Femic.	Salic.	Deficient SiO_2
rtz-monzonite	.32	.14	.08	1.53	.69	3.71	...	.77[1]	.23	.000
rtz-monzonite. ..	.32	.15	.12	1.53	.71	3.79	....	.77[1]	.23	.000
te..	.45	.17	.13	1.86	.82	4.03	.09	.76[1]	.24	—.007
rtz-diorite	.39	.08	.12	2.04	.46	4.17	....	.78[1]	.22	—.014
oro........ .. .	.45	.07	.13	1.60	.44	3.46	....	.71[2]	.29	—.003
esite (?) trachyte..	.64	.41	.18	1.25	.47	2.92	....	.61[1]	.39	—.095
oase	.67	.16	.21	1.46	.73	3.53	.31	.57[2]	.43	.000
ite.	.44	.32	.28	.72	1.16	4.28	.07	.66[1]	.34	.000
nelite-syenite.....	.64	.45	.43	.33	1.60	3.23	.10	.67[2]	.33	—.040
lite-syenite.	.85	.12	.35	.19	1.73	3.40	....	.62[2]	.38	—.165
granite.........	.23	1.9	2.18	.0	4.84	14.76	....	.94[1]	.06	.000
dinite...........	.46	.66	1.23	.70	3.46	8.72	....	.82[2]	.18	—.030
nelite-syenite	.51	.29	1.71	.24	5 59	8.80	...	.81[2]	.19	.000
ellerite.	1.3	1.3	2.4	.58	12.60	20.01	....	.76[2]	.24	.000
nelite-syenite. ...	1.3	1.5	4.6	.33	20.75	26.33	3.9	.84[2]	.16	.000
endite...........	27.0	18.0	93.0	2.0	192.	409.	....	.71[1]	.29	.000

e. [2] Femic Ca, Mg, Fe, calculated partly as orthosilicate and partly as metasilicate.

e salic components to leucite or nephelite.

TABLE XIV. ANALYSES OF MICAS AND THE ROCKS CONTAININ

	a		b		c		d		e		f		g		
	Rock.	Mica.	Rock.	Mica.	Rock.	Mica.	Rock.	Mica.	Rock.	Mica.	Rock.	Mica.	Rock.	Mica.	Ro
SiO_2	71.08	36.02 .600	66.83	35.75 .596	63.88	35.79 .596	66.91	35.62 .594	77.61	31.96 .533	60.39	32.09 .535	54.55	34.37 .574	56.
Al_2O_3 ...	15.90	18.81 .184	15.24	14.70 .144	15.84	13.70 .134	....	15.24 .149	11.94	11.93 .117	22.57	18.52 .180	19.07	6.84 .067	23.
Fe_2O_3 ...	.62	5.60 .035	2.73	4.65 .029	2.11	5.22 .032	....	4.69 .029	.55	8.06 .050	.42	19.49 .121	2.41	24.89 .156	.
FeO	1.31	14.75 .205	1.66	14.08 .195	2.59	13.72 .190	....	13.67 .190	.87	30.35 .421	2.26	14.10 196	3.12	7.47 .104	2.
MgO.....	.54	9.82 .245	1.63	12.37 .309	2.13	12.13 .303	....	12.70 .317	trace	.05 .001	.13	1.01 .025	1.98	4.05 .101	.
CaO	2.60	.65 .011	3.59	.17 .003	3.97	.05 .001	3.51	.95 .017	.31	.23 .004	.32	....	3.15	.78 .014	.
Na_2O	3.54	.38 .006	3.10	.32 .005	2.81	.15 .002	3.59	.50 .008	3.80	1.54 .025	8.44	1.55 .025	7.67	2.13 .034	7.
K_2O	4.08	9.32 .099	4.46	9.19 .098	4.23	9.09 .097	3.13	7.72 .082	4.98	8.46 .090	4.77	8.12 .086	4.84	9.03 .096	5.
H_2O+ ...	.30	2.57 .143	.56	3.64 .200	.66	3.64	....	4.36 .242	trace	4.25	.57	4.62 .256	.72	2.27 .127	.
H_2O- ...	none	....	none	1.03	.22	1.21	....	.94	.23	....	....	....	....	....	..
CO_2	trace	....	trace	....	....	....	....	....	....	....	....	....	....	....	1.
TiO_2.....	.22	1.13 .014	.54	3.16 .039	.65	3.51 .044	....	2.61 .033	.25	3.42 .043	....	....	1.40	4.68 .058	.
P_2O_5	.10	....	.18	.03	.21	.10	....	none	....	....	....	....	.74	....	..
SO_3......	none	....	none	....	.34	....	....	....	....	....	....	....	....	....	..
Cl	.02	....	.02	....	trace	.20	....	....	.	....	....	....	....	....	..
Cr_2O_3....	....	....	....	trace	....	....	....	....	....	....	....	....	.. .	....	..
NiO	....	....	....	.02	....	....	....	....	....	....	....	....	....	....	..
MnO.....	.15	.80 .011	.10	.45 .006	.07	.19 .002	....	.74 .010	trace	.21 .003	.08	1.42 .020	.17	2.41 .034	.
BaO	.04	trace	.11	.12	.09	.13	....	....	....	....	....	....	....	....	..
SrO	.02	none	.03	(?)	.02	none	....	trace	....	....	....	F. none	....	....	..
ZrO_2.....	.08	F. .26 .014	ZrO_2.04	none	....	F. .76 .032	....	....	....	....	....	....	....	....	..
	100.60	100.11	100.82	F. .17	99.82	99.59		100.00	100.54	100.46	99.95	100.92	99.82	98.92	99.
				V_2O_3.05 99.90 .07 99.83											Sp.

a) *Biotite* from *granodiorite* (grano-toscanose), El Capitan, Yosemite Valley, Cal. *A. J. S.*, Vol. VII (1899), p. 294.

b) *Biotite* from *quartz-monzonite* (grano-toscanose), Nevada Falls Trail, Yosemite Valley, Cal. *A. J. S.*, Vol. VII (1899), p. 297, and *Bull. 168, U. S. Geol. Surv.*, p. 208.

c) *Biotite* from *quartz-monzonite* (grano-amiatose), Walkerville Station, Butte, Mont. JOUR. GEOL., Vol. VII, and *Bull. 168, U. S. Geol. Surv.*, p. 116.

d) *Biotite* from *quartz-monzonite* (grano(?)toscanose), Bloods Station, Alpin Co., Cal. *A. J. S.* Vol. VII (1899), p. 294.

e) *Lepidomelane* from *granite* (grano-liparose), Cape Ann, Mass. *A. J. S.*, Vol. XXXII, 1886, p. 359. Rock analysis, H. S. WASHINGTON, JOUR. GEOL., Vol. VI, p. 793.

f) *Lepidomelane* from *nephelite-syenite* (gr
168, U. S. Geol. Surv., p. 21.

g) *Lepidomelane* from syenite-pegmatite,
analysis from *laurdalite* (laurdalose)
Eruptivgest. Kristiania geb. III, pp

h) *Lepidomelane* from (?) nephelite-syenite,
from *miascit* (grano-miaskose),
Guide Excurs. VII, Cong. Geol. Int

i) "Biotite" from monchiquite, Horberig, Obe

j) *Phlogopite* from wyomingite (phyro-wyom
A. J. S., Vol. IV (1897), p. 130, and *B*

TABLE XIVa, MOLECULAR RATIOS IN MICAS.

			$\frac{Al_2O_3}{K_2O}$	$\frac{Fe_2O_3}{K_2O}$	$\frac{MgO}{K_2O}$	$\frac{FeO}{K_2O}$	Si
a) Biotite	grano-toscanose	Granodiorite................	1.8	.33	2.47	2.07	5.
b) Biotite..........	grano-toscanose.............	Quartz-monzonite............	1.4	.28	3.15	2.00	5.
c) Biotite...............	grano-amiatose	Quartz-monzonite............	1.3	.32	3.12	1.96	6.
d) Biotite....................	no analysis	Quartz-monzonite............	1.9	.32	3.86	2.31	6.
e) Lepidomelane......	grano-liparose	Granite	1.0	.43	.0	4.67	4.
f) Lepidomelane	grano-nordmarkose...........	Nephelite-syenite	1.6	1.1	.29	2.28	4.
g) Lepidomelane...............	grano-laurdalose	Nephelite-syenite	.51	1.2	1.05	1.07	4.
h) Lepidomelane...............	grano-miaskose	Nephelite-syenite	1.4	.35	1.57	3.98	5.
i) "Biotite"...........	no analysis...........	Monchiquite.......	1.5	.15	7.42	1.42	5.
j) Phlogopite.................	phyro-wyomingose	Wyomingite	.98	.14	4.91	.10	5.

IV. ANALYSES OF MICAS AND THE ROCKS CONTAINING THEM.

	c		*d*		*e*		*f*		*g*		*h*		*i*	*j*	
ica.	Rock.	Mica.	Rock.	Mica.	Rock.	Mica.	Rock.	Mica.	Rock.	Mica.	Rock.	Mica.	Mica.	Rock.	Mica.
.75	63.88	35.79	66.91	35.62	77.61	31.96	60.39	32.09	54.55	34.37	56.26	33.24	36.42	50.23	42.56
.596		.596		.594		.533		.535		.574		.554	.607		.709
.70	15.84	13.70	....	15.24	11.94	11.93	22.57	18.52	19.07	6.84	23.59	14.90	17.92	11.22	12.18
.144		.134		.149		.117		.180		.067		.146	.175		.119
.65	2.11	5.22	....	4.69	.55	8.06	.42	19.49	2.41	24.89	.85	5.92	2.83	3.34	2.73
.029		.032		.029		.050		.121		.156		.037	.017		.012
.08	2.59	13.72	....	13.67	.87	30.35	2.26	14.10	3.12	7.47	2.61	23.57	7.04	1.84	.90
.195		.190		.190		.421		196		.104		.327	.098		.012
.37	2.13	12.13	....	12.70	trace	.05	.13	1.01	1.98	4.05	.27	5.15	20.52	7.09	22.40
.309		.303		.317		.001		.025		.101		.129	.513		.560
.17	3.97	.05	3.51	.95	.31	.23	.32	....	3.15	.78	.54	.40	....	5.99	.20
.003		.001		.017		.004				.014		.007			.003
.32	2.81	.15	3.59	.50	3.80	1.54	8.44	1.55	7.67	2.13	7.77	1.45	2.60	1.37	.44
.005		.002		.008		.025		.025		.034		.023	.042		.007
.19	4.23	9.09	3.13	7.72	4.98	8.46	4.77	8.12	4.84	9.03	5.72	7.77	6.54	9.81	10.70
.098		.097		.082		.090		.086		.096		.082	.069		.114
.64	.66	3.64	....	4.36	trace	4.25	.57	4.62	.72	2.27	.37	2.19	2.50	1.72	2.35
.200				.242				.256		.127					.130
.03	.22	1.21	....	.94	.23	....	....	....	....	....	....	....	....	.93	....
...	....	....	....	....	....	....	....	....	....		1.37	....	....	....	....
.16	.65	3.51	....	2.61	.25	3.42	....	....	1.40	4.68	.47	4.73	3.99	2.27	2.09
.039		.044		.033	....	.043			....	.058		.059	.049		.026
.03	.21	.10	....	none	....	....	....	....	.74	....	....	....	....	1.89	.06
...	.34	....	....	....	....	....	....	....	....	....	....	....	....	.74	....
...	trace	.20	....	....	.	....	....	....	....	....	....	....	....	.03	....
ace	....	....	....	....	....	....	....	....	.. .	....	....	....	....	.10	.73
															.005
.02	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....
.45	.07	.19	....	.74	trace	.21	.08	1.42	.17	2.41	.09	.95	....	.05	....
.006		.002		.010		.003		.020		.034		.013			
.12	.09	.13	....	....	....	....	....	....	....	....	....		....	1.23	1.00
															.006
(?)	.02	none	....	trace	....	....	....	F. none	....	....	....	....	....	SrO .24	trace
one	....	F. .76	....	....	....	....	....	....	....	....	....	...	....	Di_2O_3 .03	....
		.032												F. .50	2.46
.17	99.82	99.59		100.00	100.54	100.46	99.95	100.92	99.82	98.92	99.91	100.27	100.36	100.62	100.80
														.22	1.03
O_3.05											Sp. gr..	3.084		100.40	99.77
.90															
.07															
.83															

canose), El Capitan, Yosemite Valley, Cal. *A.*

ano-toscanose), Nevada Falls Trail, Yosemite
II (1899), p. 297, and *Bull. 168, U. S. Geol.*

no-amiatose), Walkerville Station, Butte, Mont.
. *168, U. S. Geol. Surv.*, p. 116.

rano(?)toscanose), Bloods Station, Alpin Co.,
p. 294.

-liparose), Cape Ann, Mass. *A. J. S.*, Vol.
ysis, H. S. WASHINGTON, JOUR. GEOL., Vol. VI,

f) *Lepidomelane* from ***nephelite-syenite*** (grano-nordmarkose), Litchfield, Me. *Bull. 168, U. S. Geol. Surv.*, p. 21.

g) *Lepidomelane* from syenite-pegmatite, Barkevik, Langesundfjord, Norway; rock analysis from *laurdalite* (laurdalose), north of Löve, Laugenthal. BRÖGGER, *Eruptivgest. Kristiania geb.* III, pp. 19 and 34.

h) *Lepidomelane* from (?) nephelite-syenite, Miask, Dana, System, p. 630; rock analysis from *miascit* (grano-miaskose), Mt. Lobatchia, Siberia. A. KARPINSKI, *Guide Excurs. VII, Cong. Geol. Int.* V (1897), p. 22.

i) "Biotite" from monchiquite, Horberig, Oberbergen. ROSENBUSCH, *El. Gest.*, p. 234.

j) *Phlogopite* from wyomingite (phyro-wyomingose), Boar's Tusk, Leucite Hills, Wyo. *A. J. S.*, Vol. IV (1897), p. 130, and *Bull. 168, U. S. Geol Surv.*, p. 85.

TABLE XIVa, MOLECULAR RATIOS IN MICAS.

		$\frac{Al_2O_3}{K_2O}$	$\frac{Fe_2O_3}{K_2O}$	$\frac{MgO}{K_2O}$	$\frac{FeO}{K_2O}$	$\frac{SiO_2}{K_2O}$	$\frac{TiO_2}{K_2O}$	Femic.	Salic.	Deficient. SiO_2
-toscanose	Granodiorite	1.8	.33	2.47	2.07	5.71	.13	.54	.46	—.034
-toscanose	Quartz-monzonite	1.4	.28	3.15	2.00	5.78	.38	.52	.48	—.033
-amiatose	Quartz-monzonite	1.3	.32	3.12	1.96	6.01	.44	.52	.48	—.005
alysis	Quartz-monzonite	1.9	.32	3.86	2.31	6.60	.36	.54	.46	—.011
-liparose	Granite	1.0	.43	.0	4.67	4.63	.37	.55	.45	—.050
-nordmarkose	Nephelite-syenite	1.6	1.1	.29	2.28	4.82	...	.40	.60	.000
-laurdalose	Nephelite-syenite	.51	1.2	1.05	1.07	4.26	.44	.62	.38	.000
-miaskose	Nephelite-syenite	1.4	.35	1.57	3.98	5.27	.56	.53	.47	—.020
alysis	Monchiquite	1.5	.15	7.42	1.42	5.46	.44	.52	.48	—.025
-wyomingose	Wyomingite	.98	.14	4.91	.10	5.86	.21	.49	.51	—.029